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RECLAMATION
A MULTI-FACETED ACTIVITY

PROCEEDINGS
OF THE
SEVENTH ANNUAL MEETING

SYDNEY, NOVA SCOTIA
AUGUST 29 - SEPTEMBER 1, 1982

CLRA

CANADIAN LAND RECLAMATION ASSOCIATION
BOX 682, GUELPH, ONTARIO, CANADA, N1H 6L3

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ORGANIZED BY THE
ATLANTIC CONFERENCE COMMITTEE

ISSN 0705-5927

FOREWARD

Land reclamation and the rehabilitation of devastated or disturbed land to a useful, socially acceptable and biologically productive state requires the successful application of many skills and the solution of a great number of problems. Accordingly, the theme of the seventh annual meeting "A Multi-Faceted Activity", reflects this diversity. For convenience the wide range of topics discussed have been grouped into four technical sessions:

PLANNING

MICROBIOLOGY

GENERAL

COAL

These proceedings could not have been made available for the meeting in Sydney without the cooperation of the authors in providing written versions of their talks in advance of the conference. Their help is much appreciated. Copies of the proceedings can be obtained from the Guelph office.

D. Abbott
Editor

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SESSION THREE - GENERAL

Chairman - J. E. Winch, Professor
Dept. Crop Science, Guelph University
Guelph, Ont., Canada

SESSION FOUR - COAL

Chairman - G. T. Boutilier, Horticulture Manager
Cape Breton Development Corporation

Canadian Land Reclamation Association
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THE RECLAMATION ACTIVITIES OF ALBERTA ENVIRONMENT

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THE RECLAMATION ACTIVITIES OF ALBERTA ENVIRONMENT

By

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Head, Reclamation Branch
Alberta Environment

ABSTRACT

Ineffective surface reclamation legislation for many years left thousands of hectares of Alberta landscape scarred and abandoned after being disturbed by man's activities.

In an effort to reclaim some of these disturbed areas, a Land Reclamation Program was established in 1973 by the Alberta government with a budget of $600,000.

Administered by the Reclamation Branch of Alberta Environment's Land Reclamation Division, the program has since developed into a $5-million per year operation. This consists of a $3.5 million annual operational reclamation program actually reclaiming derelict lands and a $1.5 million annual reclamation research fund to find ways for improving and/or developing all aspects of land reclamation.

To date, the program has returned to productive use more than 1,200 individual parcels of land in the province. Without the program, these areas would have remained dangerous, weed-infested, useless sections of land.

INTRODUCTION

In Alberta, before effective surface reclamation legislation, (The Land Surface Conservation and Reclamation Act in 1973) many acres of lands throughout the Province were disturbed as a result of mineral and aggregate mining, oil and gas exploration and extraction, waste disposal, and the construction of required communications, transmission and transportation facilities and processing sites. These activities have resulted in some lands becoming derelict and devoid of productive vegetation, leading to wind and water erosion which cause further nonproductive processes to degrade the land, water, vegetative and animal resources. In addition some lands have deteriorated to become noxious weed seed plantations, human safety hazards, and scars on Alberta's scenic landscape.

The above factors led to the establishment of the present land reclamation program which is administered by the Reclamation Branch of the Department of the Environment.

The primary objective of the program is to fund reclamation projects and restore those lands for which no responsible operator can be ascertained in order that the land can be returned to a biophysically productive state.

Secondary objectives of the program are:

(a) The creation of a progressive land management attitude among industrial land users in particular and Albertans in general which can be passed on to future generations.

(b) The aesthetic improvement of Alberta's landscape.

(c) The employment of Albertans.

THE LAND RECLAMATION PROGRAM

The Alberta Land Reclamation Program was born in late 1973 as a result of a request by the Department of Advanced Education to the Department of the Environment for suitable sites to train heavy equipment operators. As a result of this request, the two departments worked together to organize a program for reclaiming two abandoned sites in the province.

The Department of the Environment purchased two abandoned coal strip mines. The first was a 48 acre site at Three Hills in central Alberta. This site was mined from 1909 to 1954 and then abandoned. The second was the Bow City site, mined from 1910 to 1944, it consisted of 270 acres of mine spoil and water bodies.

The reclamation of these two sites along with 5 small garbage dumps were the total program for 1974 and cost $305,000. for the land levelling.

In the second year of the program, an invitation to municipalities, towns and villages was sent out asking them for proposals for the reclamation of public lands, particularly abandoned gravel, sand, coal and land-fill pits and erosion problems. Special consideration was given to sites which would be restored to a "higher use", eg. parks, crop land, urban use, wildlife habitat, etc.

Reclamation projects that met the criteria of the Department were funded by contracting the work to the Applicant (Local Authority).

The criteria which had to be met in order to enter into a contract were:

1. Funds were to be used in reclaiming public lands (crown, municipal, or tax recovery land owned by the Department of Municipal Affairs).

2. Where possible, work was to be done by a local private contractor.

3. A maximum of $35,000. was to be paid to each municipality to ensure that benefits accrued to all parts of the Province.

4. Reclamation of private lands would require a transfer of ownership to the crown or municipality.

5. The priorities for funding were sites which would demonstrate before and after effects of mans activities and would be in the public interest and useful for education purposes.

Other government departments with jurisdiction over crown lands were included in the program: the Forestry Division of the Department of Energy and Natural Resources, whose list of projects includes abandoned access roads and seismic lines, landfill and sawmill sites, mine sites, communication sites, and stream bank crossings; the Lands Division of the Department of Energy and Natural Resources whose reclamation projects dealt with abandoned gravel pits and litter problems on crown lands; the Department of Transportation with abandoned roadways and gravel pits and, finally, the Provincial Parks Department whose sites are primarily abandoned roadways and eroded areas within provincial parks.

By the end of 1975, some 126 projects had been started which reclaimed approximately 1000 acres of land for agricultural, recreational and wildlife use at an investment of $761,636.00. The tables at the end of this paper summarize the types and costs of the projects for the years 1975-82.

Some problems were encountered with the contracts type of arrangement: (1) there was no continuity of reclamation among municipalities; (2) municipalities put a low priority on reclaiming these lands which meant a carry over of projects to the following year. This in turn upset budget estimates and spending; (3) monies were also misused, although not extensively enough to warrant a change in procedure.

The procedure for municipal projects was changed for the year 1977 to eliminate contracts completely. Instead, municipalities were asked to submit applications to the Reclamation Branch along with agreements allowing the branch the

right of entry to do reclamation work. They were also required to submit proof of land ownership in the form of a copy of the land title. This method of administration proved very effective as it left all phases of reclamation work from the planning stage through to completion totally in the hands of the Reclamation Branch. The Reclamation Branch with the aid of Reclamation Officers took over all facets of Reclamation of derelict lands in the white zone.

The Land Reclamation Program as it exists today consists of four stages of development from start to finish.

The first stage is application-screening. At this stage applications for reclamation projects are received from municipalities and other government departments, reviewed by the relamation engineers and accepted or rejected on the basis of information supplied by the applicant.

In the second stage the municipal project sites which meet the criteria for reclamation projects are inspected by the Reclamation Engineer and Reclamation Technologist. At this stage a reclamation plan is drawn up, a work method instituted, equipment selection made and a cost estimate done.

The Reclamation Technologist takes over the third stage, which is the actual physical work, and is responsible for hiring a contractor with suitable equipment and supervising the day to day operations. After the earthwork is completed, the seeding and fertilizing of the site is done in one of two ways depending on site conditions: (1) by conventional farming methods where farm machinery can be used, or (2) hydroseeding on areas that may be inaccessible to conventional equipment or that may pose soils problems from the standpoint of vegetation growth.

The fourth and final stage is the follow-up inspection done a year later. The site is evaluated as to the success of reclamation and additional work which may be required to bring the site up to a standard satisfactory to the department, is requisitioned. After this has been done, responsibility for maintenance passes to the municipality.

To give you more insight into the reclamation of abandoned lands in the Province, I will outline the procedures used to reclaim (1) abandoned garbage dumps, (2) abandoned sewage lagoons and (3) abandoned mines and mine hazards. These constitute the majority of the projects which are handled directly by the Reclamation Branch.

Abandoned garbage dumps are usually the most difficult and on a per acre basis, the most expensive projects to reclaim. As garbage was dumped at random on the site it is almost impossible to conduct the work in an organized progressive manner. The

loose surface garbage is usually piled up to one end of the dump site and then a trench or several trenches are excavated in order to provide a burial site for the piled up garbage. The garbage is dozed into the trenches, compacted with the dozer and covered with a minimum of two feet of clean fill which was obtained from the excavation of trenches. The entire area is then contoured to provide proper drainage and trimmed up. Any garbage remaining on the surface is hand picked and disposed. The site is then cultivated, seeded and fertilized.

Sewage lagoons are first drained of effluent during spring run-off and allowed to dry as much as possible before the start of reclamation. Different approaches are used, depending on the size of lagoon and the amount of sludge present. On larger lagoons with anerobic cells which are full of sludge a method is used whereby the area around the anerobic cell is levelled off. The berms of the anerobic cells are then dozed into the cells-in effect squeezing the sludge over the adjacent areas which were previously levelled. The sludge is then spread out over as large an area as possible and allowed to dry. The lagoon site is then trimmed up to provide proper drainage and cultivated to work the sludge into the soil. Last but not least it is seeded.

Reclamation of abandoned coal mines are projects which do not offer much in the way of selection or planning for the Reclamation Branch. The mines during their years of operation were not required to preplan, selectively strip and stockpile topsoil and subsoils, or recontour the spoil piles upon completion of mining. The most that can be done with this situation is to level the piles and establish proper drainage patterns in order to bring the land back to productive use. Our success at reclamation (revegetation) of mines of this nature has ranged from excellent for spoil piles with minimal or no soil limitations on plant growth to mediocre on mine sites with spoil piles that have severe limiting factors on plant growth.

OTHER TYPES OF PROJECTS

To date the Land Reclamation Program, including the sites reclaimed by other government departments, has reclaimed more than 1,200 individual sites ranging in size from 1/2 acre garbage dumps to abandoned strip mines up to 400 acres in size. The total investment to date of both operational reclamation and reclamation research is in excess of $14,000,000. This program has put derelict land back into productive use such as agricultural land for crop production, much needed park land, residential subdivision development, and wildlife refuge. The success and popularity of the program with the municipalities in the Province has assured the continuation of the program for at least the next 3 years.

NUMBER OF RECLAMATION PROJECTS AND APPROXIMATE COSTS - 1975

Nature of Industrial Uses		Municipal Purchased		Public		Green Area		
Access Roads	(1)	7,090.45	(1)	10,990.00	(13)	10,000.00	(15)	
Landfill and Mill Sites	(7)	19,984.90	(12)	8,130.00	(10)	8,000.00	(29)	
Mine Sites	(5)	425,611.33			(1)	11,000.00	(6)	1
Communication Sites					(4)	20,000.00	(4)	
Sand & Gravel Sites	(5)	77,867.98	(6)	81,255.97	(34)	20,000.00	(45)	1
Seismic Lines					(12)	8,000.00	(12)	
Streambank Crossings					(9)	5,000.00	(9)	
Oil Sands Sites	(1)	45,670.86					(1)	
Mineral Surface Leases			(1)	35.00	(4)	3,000.00	(5)	
Total	(19)	576,225.52	(20)	100,410.97	(87)	85,000.00	(126)	7

RECLAMATION PROJECTS AND APPROXIMATE COSTS - 1976

Nature of Industrial Uses		Municipal Purchased		Public		Green Area	
Access Roads			(1)	125.00	(7)	34,328.23	(8)
Landfill Sites	(7)	15,354.48			(2)	3,627.58	(9)
Mine Sites	(7)	447647.89			(1)	83,055.24	(8)
Sand & Gravel Sites	(7)	12,789.10	(17)	10,518.20	(3)	22,000.00	(27)
Seismic Lines			(1)	3,400.00	(4)	28,000.00	(5)
Streambank Crossings					(1)	1,066.98	(1)
Surface Leases			(2)	2,375.00			(2)
Erosion Sites			(2)	3,098.00			(2)
Abandoned Airstripes					(1)	1,953.74	(1)
[illegible]	(21)	175,791.47	(23)	20,016.20	(19)	174,031.77	(63)

RECLAMATION PROJECTS AND APPROXIMATE EXPENDITURES - 1977

Nature of Industrial Uses	Municipal	Public	Green Area	Total
Access Roads		(3) 37,693.00	(7) 171,955.54	(10) 209,648.54
Sewage Lagoons	(9) 110,062.71			(9) 110,062.71
Garbage Pits	(14) 112,170.02	(2) 6,444.37	(1) 5,507.11	(17) 124,121.50
	(9) 24,298.47*		(1) 3,417.00*	(10) 27,715.47*
Mine Hazards Sites	(42) 461,725.06	(1) 1,065.00		(43) 462,790.06
		(1) 60,955.50*		(1) 60,955.50*
Sand & Gravel Sites	(2) 3,279.10	(45) 478,903.50*	(11) 20,358.62	(58) 502,541.22
Seismic Lines		(1) 400.00		(1) 400.00
Abandoned Airstrip		(1) 2,312.80		(1) 2,312.80
Total	(76) 711,535.36	(54) 587,774.17	(20) 201,238.27	(150) 1,500,547.80

RECLAMATION PROJECTS AND UNAUDITED EXPENDITURES FOR 1978

Nature of Industrial Uses	Municipal	Public	Green Area	Total
Access Roads		(3) 26,312.77	(16) 84,894.90	111,207.67
			(2) 3,023.35*	3,023.35*
Sewage Lagoon	(28) 473,310.31			473,310.31
Garbage Pits	(29) 202,678.71	(4) 16,025.18	(10) 5,461.05	224,164.94
			(9) 9,192.01*	9,192.01*
Mine Hazards Sites	(22) 194,942.75			194,942.75
Sand & Gravel Sites	(9) 151,081.73	(8) 52,374.87	(5) 11,473.97	214,930.57
Seismic Lines		(1) 4,000.00	(4) 27,069.59	31,069.59
Water Storage Sites	(2) 8,575.30			8,575.30
Borrow Pit Sites	(2) 4,949.50			4,949.50
Abandoned Recreation Site	(1) 3,590.04			3,590.04
Erosion Control Projects		(1) 5,317.00*	(1) 7,109.68*	12,426.68
Industrial Sites		(3) 1,952.40	(85) 141,030.69	142,983.09
Coal Exploration Trails			(3) 66,905.51	66,905.51
Well Sites			(5) 19,038.62	19,038.62
Tower Site			(1) 755.47	755.47
Reclamation Research				730,071.03
Total	(93) 1,039,128.34	(20) 105,982.22	(140) 375,954.84	(253) 2,251,136.43

* Not Alberta Heritage Savings Trust Fund

RECLAMATION PROJECTS AND APPROXIMATE EXPENDITURES - 1979

Nature of Industrial Use	Municipal		Public		Green Area		Tota	
Access Roads	(6)	154,149.69			(14)	50,094.83	(20)	204,2
Sewage Lagoons	(23)	354,927.35					(23)	354,9
Garbage Pits	(28)	268,429.38			(12)	11,380.18	(40)	279,8
Mine Hazards Sites	(20)	136,084.48					(20)	136,0
Sand & Gravel Sites	(5)	74,492.77			(4)	5,015.47	(9)	79,5
Seismic Lines					(7)	28,788.92	(7)	28,
Water Reservoirs	(3)	29,526.73	(1)	4,330.00			(4)	33,
Industrial Sites					(197)	362,210.25	(197)	362,
Dams	(1)	2,417.03					(1)	2,
Refinery Site	(1)	30,986.47					(1)	30,
Abandoned Bridges					(3)	2,176.08	(3)	2,
Coal Mines	(1)	50,597.00	(1)	20,475.00			(2)	71,
Total	(88)	1,101,610.90	(2)	24,805.00	(237)	459,665.73	(327)	1,586,

RECLAMATION PROJECTS AND APPROXIMATE EXPENDITURES - 1980 - 81

Nature of Industrial Use	Municipal	Public	Green Area	Total
Access Roads and Abandoned	(2) 25,058.47		(12) 117,385.10	(14) 142,443.5
Sewage Lagoons	(16) 313,260.38			(16) 313,260.3
Garbage Pits	(26) 323,470.01		(4) 8,335.00	(30) 331,805.0
Mine Hazards	(6) 15,358.06			(6) 15,358.0
Gravel Pits	(11) 137,310.50	(2) 4,700.00	(2) 5,383.02	(15) 147,393.5
Seismic Lines			(10) 59,619.95	(10) 59,519.9
Water Reservoirs	(3) 224,997.69		(1) 145,010.05	(4) 370,007.7
Industrial Sites	(1) 1,378.39	(1) 4,500.00	(25) 125,759.31	(27) 131,637.7
Mine Sites	(6) 538,378.48			(6) 538,378.4
Total	(71)1,579,211.98	(3) 9,200.00	(54) 461,492.43	(128)2,049,904.4

RECLAMATION PROJECTS AND APPROXIMATE EXPENDITURES - 1981 - 82

Nature of Industrial Use	Municipal	Public	Green Area	Total
Access Roads			(15) 273,475.00	(15) 273,475.00
Sewage Lagoons	(22) 515,220.25			(22) 515,220.25
Garbage Dumps	(24) 251,817.25		(1) 324.00	(25) 252,141.25
Mine Hazards	(5) 3,631.15			(5) 3,631.15
Sand & Gravel	(6) 264,127.00	(5) 15,200.00	(2) 7,980.00	(13) 287,307.00
Seismic Lines			(7) 69,413.00	(7) 69,413.00
Water Reservoirs	(3) 9,540.78			(3) 9,540.78
Industrial Sites	(6) 50,017.96		(31) 90,215.00	(37) 140,232.96
Dams				
Refineries	(2) 36,373.30			(2) 36,373.30
Abandoned Bridges	(6) 200,000.00			(6) 200,000.00
Coal Mines	(9) 343,369.57			(9) 343,369.57
Total	(83) 1,674,097.26	(5) 15,200.00	(56) 441,677.00	(144) 2,130,704.26

REHABILITATION PLANNING FOR PIT MINING REGIONS

by

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ABSTRACT

The source of aggregate for many of Canada's metropolitan areas is limited to a few localities within a restricted radius. It is common to find a large number of operators working one large gravel deposit simultaneously. Although many provincial and municipal governments have controls on mining, these are commonly site specific, directed to ensure each operator carries out an approved rehabilitation plan. In pit mining regions, there is also a need for planning of resource extraction and landscape transformation at a broader level, beyond the limits of a single property. What will be the cumulative environmental impact of mining? How will development of each mine site relate to adjoining mining properties, municipal roadways and non-mining properties? How will post-mining land uses relate? What is the optimum phasing of excavation and rehabilitation in the region?

Answers to these questions are necessary in order for a responsible public agency to evaluate the adequacy of submitted rehabilitation plans, to provide direction to operators preparing such plans (through central co-ordination), and to exercise controls where the overall impact of mining would be a source of undue environmental degradation. A process for rehabilitation planning at this comprehensive level has been developed, and is being applied to pit mining regions in Manitoba. The conflicts being addressed and the advantages of such programs are discussed in relation to the Manitoba experience.

1.0 Introduction:

The concept of planning for progressive rehabilitation at indvidual pits and quarries has been widely advocated since the 1960's, and its advantages have been clearly demonstrated in numerous case studies. (Bauer, 1965; Baxter, 1969; Schellie, 1963; Coates, 1979). However, in the administration of development controls over surface mining, there is also a need for planning at a broader level, beyond the limits of a single property. The purpose of such comprehensive planning is to establish rational controls on land use development in the mining region, including performance criteria related to mining and rehabilitation. The necessary scope of such programs and the potential advantages are outlined in this paper.

2.0 Background and Problem Statement:

2.1 The Aggregate Dilemma

It is clearly advantageous for the public as a whole to make the optimum use of available mineral aggregate reserves. Sand and gravel are a non-renewable resource, essential to virtually all construction activity. Diminishment of those reserves close to our towns and cities will ultimately result in higher costs to the public for all projects, particularly roads and buildings. While eventual depletion is inevitable, the resultant inflation of construction costs can be unduly accelerated by careless land planning decisions which preclude mining before the aggregate is extracted.

At the same time, however, it has become widely recognized that the mining of aggregate may be a source of conflict for the local community, where it can cause a substantial negative impact. Adjoining property holders and municipal officials are most frequently concerned over issues such as:

i) Encroachment of excavation beyond joint property boundaries;
ii) Lowering of the groundwater table or impairment of water quality;
iii) Noise, dust and visual disamenity associated with the excavation or with a derelict post-mining landscape;

iv) The creation of dangerous conditions or nuisance problems (weeds, unregulated off-road vehicle use, etc.) on the mine property;

v) Long term loss of productivity (and associated public revenue) where a mine landscape remains in a derelict condition over a long term;

vi) Depreciation of adjoining property values as a consequence of any or all of the above factors.

In the absence of clear measures to mitigate these problems, municipalities and ratepayer groups can become motivated to discourage and limit mining activity. This is the real basis of the 'aggregate dilemma', when the general public's interests are pitted against the interests of the local public (McLellan, 1975; National Research Council, 1980).

2.2 The Need for Rehabilitation Planning at a Regional Level

Across Canada and the United States the response to this 'aggregate dilemma' has been enactment of different forms of statutory and regulatory controls, directed to minimize the impact of surface mining and require some form of landscape restoration. (Ahearn, 1964; Hogan, 1978). In some areas, standards have been prescribed governing such things as the setback of excavation from a property boundary, the hours of mine operation, or the minimum slope gradients permitted in the post-mining landscape. Where these 'minimum standards' are imposed over a broad area of jurisdiction, however, they may not be suited to the range of circumstances encountered. They can result in either inadequate protection of the environment or a stifling of the potential for rehabilitation.

An alternative approach has been to require each mine operator to prepare a plan of mine operation and rehabilitation for his property. These site plans are then submitted to the regulatory authority for 'conditional approval'. While this

allows the establishment of site specific controls, it is not a full solution to the problem. The regulatory agency must have a rational basis on which to evaluate each plan, and these criteria should be formally documented. It is only fair that the 'rules of the game' are made known to all participants.

It is becoming increasingly apparent, therefore, that there is a need for planning of resource extraction and landscape transformation at a broader level, beyond the limits of a single property. Gravel deposits are rarely owned and controlled by one mining company. The geologic processes from which sand and gravel deposits are derived acted over vast areas of land and it is common to find a large number of operators working one deposit simultaneously. While the preparation of individual site plans for mining and rehabilitation of each property is essential, public authorities must have some rational and equitable basis:

i) to evaluate the adequacy and appropriateness of each plan;
ii) to provide direction and guidance to operators preparing such plans through central co-ordination;
iii) to exercise controls on the extent and direction of future mining of the deposit, particularly where it will be a source of undue environmental degradation;
iv) to control all land development adjoining existing and future mining areas, in order to prevent future conflicts.

3.0 A Model Process for Comprehensive Rehabilitation Planning

A comprehensive planning program is required to provide a decision making framework and environmental management guidelines which will direct the efforts of all participants. Individual rehabilitation plans are a component of such a program, but they should be both prepared and evaluated in the context of an overall strategy.

The flow chart in Figure 1 outlines the essential components of any comprehensive rehabilitation planning program. Three distinct phases may be identified.

The first phase addresses the mineral deposit as a whole. On the basis of a comprehensive inventory of site conditions, opportunities and constraints are identified and clear guidelines are established to direct site planning.

The second phase is that of individual site planning. Each operator is expected to plan his individual mine operation and progressive reclamation program within the context of the guidelines established in Phase I. These plans are reviewed by the regulatory agencies, also using the Phase I guidelines as criteria.

The final phase is actual implementation of the individual plans and the realization of the objectives.

Given the many variable factors and unknowns, it would be unrealistic to assume a simplistic linear planning program. The process must include intervals of reassessment, and accommodate changes over time resulting from refinement of the data base, shifts in goal priority and correction of inaccuracies. These may be initiated at any point, as indicated in the flow chart. If the program becomes too inflexible to accept change, it will quickly become self-defeating, frustrating all the parties involved.

The initial phase of this program, which examines a pit mining region as a whole, has not received a great deal of emphasis in the past. A study of the Villeneuve mining region outside Edmonton addressed this problem, and made recommendations regarding reclamation standards and post-mining development. (G.R. Shelley & Associates, 1977). No doubt there has been planning at this level in other provinces, at least at the municipal level. However, the author is not aware of any documentation, sharing specific successes or shortcomings.

Fig.1: A Comprehensive Rehabilitation Planning Process

Stage	Component	Reassessment Factor
Phase I		
1. Data Inventory and Synthesis	i) Environmental Factors - Geology - Soils - Vegetation - Topography - Groundwater	— New Information Uncovered
2. Identification of Opportunities and Constraints	i) Site Planning Considerations ii) Environmental Management Criteria	— Insufficient Information
3. Development of Rehabilitation Strategy and Management Guidelines	i) Concept ii) Guidelines iii) Phasing Priorities	— Changes Required Upon Review by the Local Public, Mine Operators, and Regulatory Agencies
Phase II		
1. Preparation of Site Plans By	i) Detailed Site Inventory and Analysis ii) Develop Mining and Rehabilitation Plans in Context of Guidelines iii) Submit for Review or Authorization	— Inadequacies of Guidelines Identified. Appeal for Change
2. Site Plan Reviewed by Regulatory Agencies	i) Approve or Disallow Based on Compliance with Regional Strategy and Management Guidelines	— Recognize Inadequacies of Guidelines
Phase III		
1. Implementation	i) Progressive Rehabilitation of Mine Property Carried Out in Accordance with Plan	— Change to Site Plans Requested

In Manitoba, the earliest attempt to formally conduct such a program focused on a major gravel deposit of Crown land, located ten miles east of the town of Beausejour. In 1978 this region had eight major quarry leases (recently increased to twenty-six) and three pit areas operated exclusively by Crown agencies. It represents one of the largest remaining gravel deposits in the Winnipeg region and is expected to become increasingly important as more local reserves are diminished.

More recently, a planning program has been initiated for a region located immediately northeast of the City of Winnipeg. This area has historically been the main source of aggregate for the city. Thirty-five separate mining properties have been opened for excavation, within a five mile radius. Unlike the Beausejour region, most of this property is privately owned and subject to municipal land development controls as well as provincial regulation.

The purpose of this paper is not to give a detailed history of these projects, but to broadly outline the advantages which can be derived from such regional planning for mining and rehabilitation. The Manitoba experience is drawn upon by way of example.

4.0 Potential Advantages of Comprehensive Planning

4.1 Prediction of Landscape Transformation

The central purpose of geologic investigations at a regional level is to define the configuration of the entire mineral deposit. Set in the context of existing topography, this allows the projection of the ultimate configuration of the post-mining landscape. It provides crude dimensions of the potential lateral and vertical extent of excavation. Where will lakes be created by mining below the water table? Where will critical shore zones be located? What volumes of overburden and reject material can be expected for backfilling functions? Where will extensive elevation changes occur?

In many instances, this projection of the ultimate configuration of the landscape will be an approximation. The variability within a geologic formation, unforeseen changes in the economic value of material over time, and improvements to mining technology will all affect the extent of mining in a region.

This shortcoming necessitates that any regional planning program includes regular updating and reassessment, as geologic information is refined over time. Planning criteria based on the geology must also be applied in a form which has flexibility.

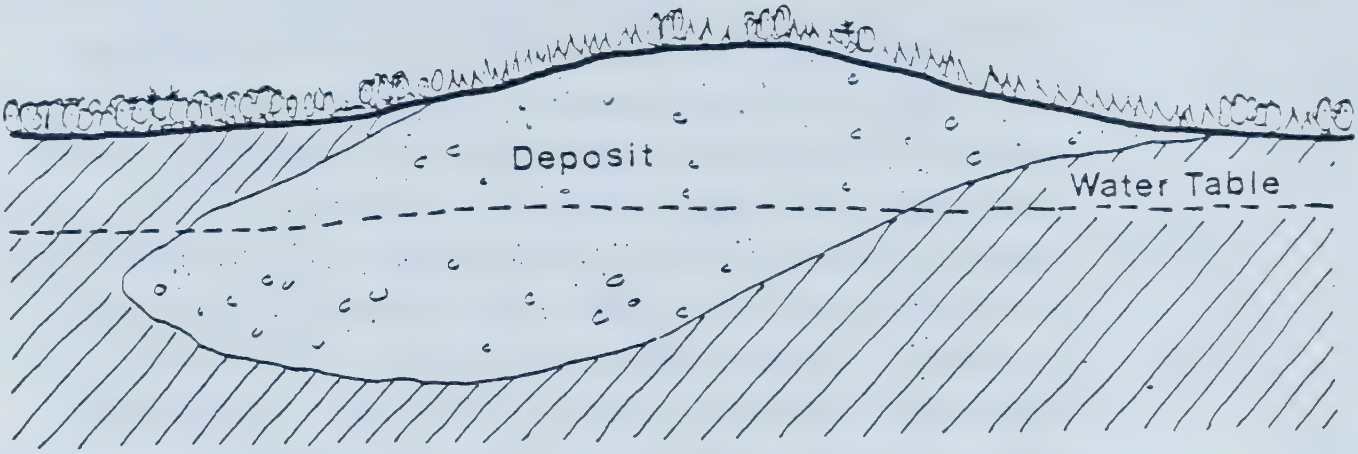
4.2 Limitations on Mining to Prevent Environmental Degradation

The model of the ultimate anticipated extent of mining should be considered in the context of other environmental parameters such as groundwater, soils and vegetation patterns. The purpose of such an analysis is to systematically identify all locations where mining should be prohibited in lateral extent or limited in depth, to prevent undue degradation of the environment.

For example, it may be necessary to prohibit mining in a locality in order to preserve a valuable ecological site. Special setback distances are necessary adjoining lakes and and rivers. Other limitations may be conditional, such as a requirement to protect high quality agricultural soils.

The potential impact of mining on groundwater conditions is most often a controversial issue, and should receive special attention. Where mining occurs below the water table it usually results in the formation of a new lake, fed only by the surface drainage basin of the pit and the lateral movement of groundwater (Figure 2). The dimensions of these features can be impressive.

Before :



After :

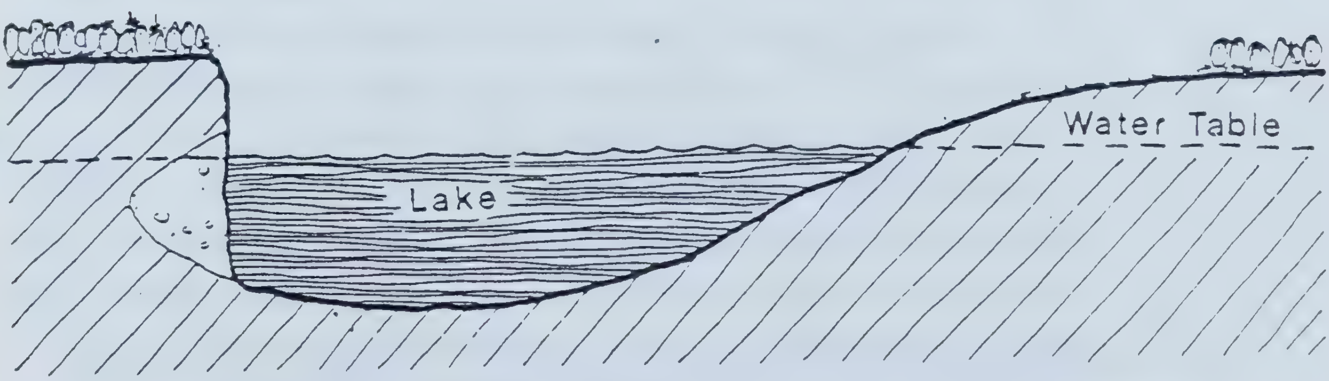


Fig.2 : Formation Of Groundwater Lakes

In Manitoba, for example, one lake may ultimately extend over 100 hectares in area, with over four kilometres of shoreline. Outside the City of Winnipeg a series of smaller lakes will be created, but their depth may exceed 30 metres in places.

These lake features exhibit unique physical and biological qualities, representing opportunities for reclamation. Prediction of the water elevation, and associated shore zone is essential in order to take full advantage of these opportunities. On the other hand, such lakes can be extremely sensitive to pollution. The water may be replenished at a very slow rate limiting the carrying capacity of the lake. (Mulamoottil, 1975). This will depend on such factors as the volume of water, rate of groundwater movement (Table 1), and the susceptibility to thermal stratification. Contaminants entering such lakes also have the potential to move through the groundwater system and to affect the wells of local property owners. Petroleum is particularly hazardous in this context, since as little as 0.5 lbs. will render 100,000 gallons of water unpalatable for human consumption.

Another concern frequently expressed by local residents adjoining a pit is that mining will affect the water level in their wells. A local drawdown may occur in the area of the pit during mining due to the net loss of water (Figure 3). After mining, evaporation loss may be significant, depending on the total surface area of the lakes developed in the region. The size of the aquifer and the permeability of the soils are important factors to consider in such an assessment. In the Beausejour region of Manitoba the aquifer is of such a size that fluctuations of the groundwater level are not anticipated to be a problem. However, the relationship of the deposit to the existing topography and groundwater table was found to be critical. As noted in Figure 4, future mining could create a new surface water channel if it intersects the groundwater table on a hillside. This could have a substantial negative impact off

Table 1: Permeability of Various Soil Types

Soil Types	Permeability (Feet Per Day)
Coarse Sand	394
Sand	39
Fine Sand	16
Very Fine Sand	8
Loamy Sand	4
Sandy Loam	0.79
Very Fine Sandy Loam	0.39
Loam	0.16
Silt Loam	0.079
Silty Clay Loam	0.039
Silty Clay	0.0079
Clay	0.0039

Source: K.L. Schellie, Sand and Gravel Operations - A Transitional Land Use, p. 1972.

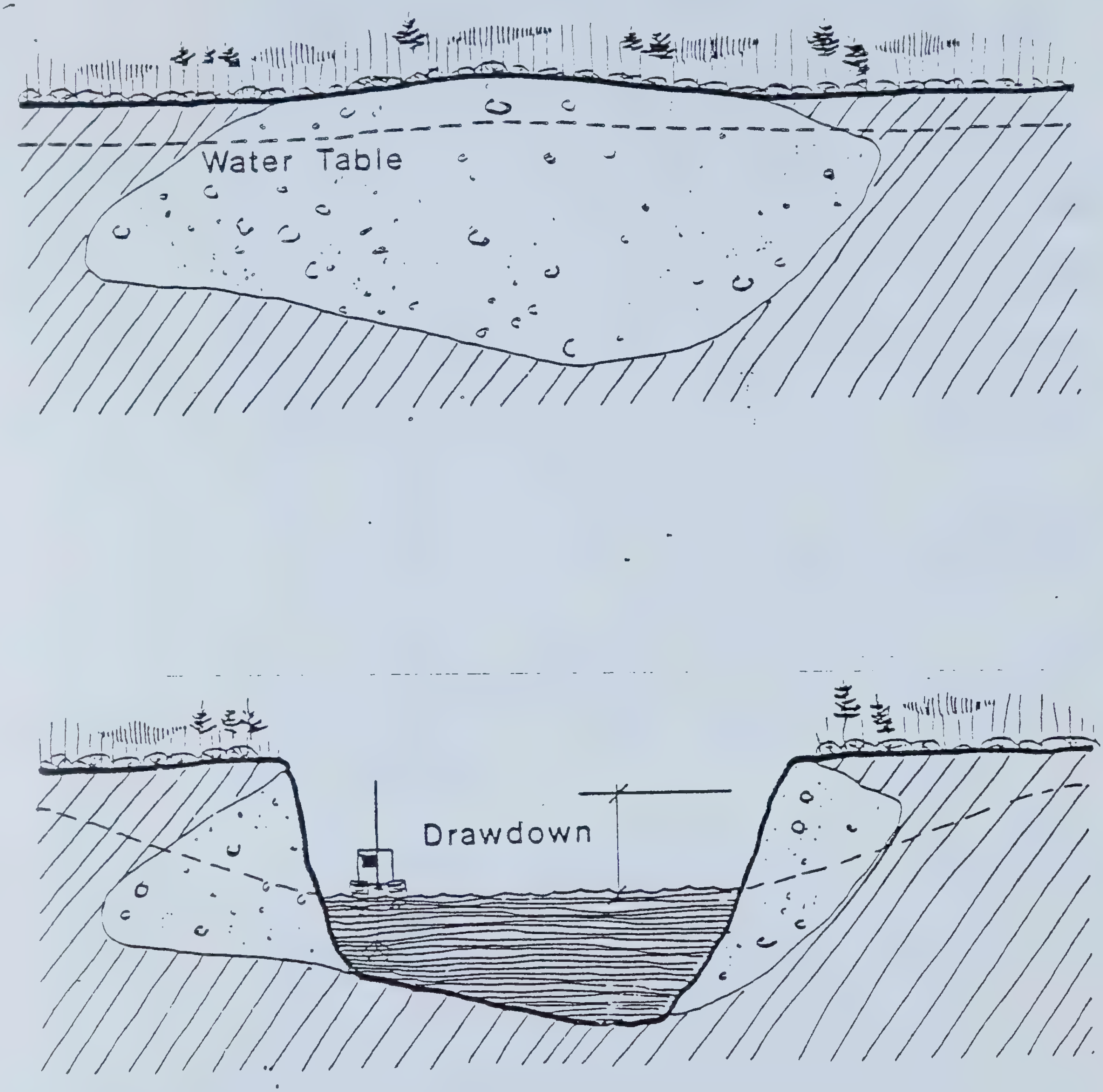


Fig 3: Local Drawdown Of The Groundwater Table Due To Mining

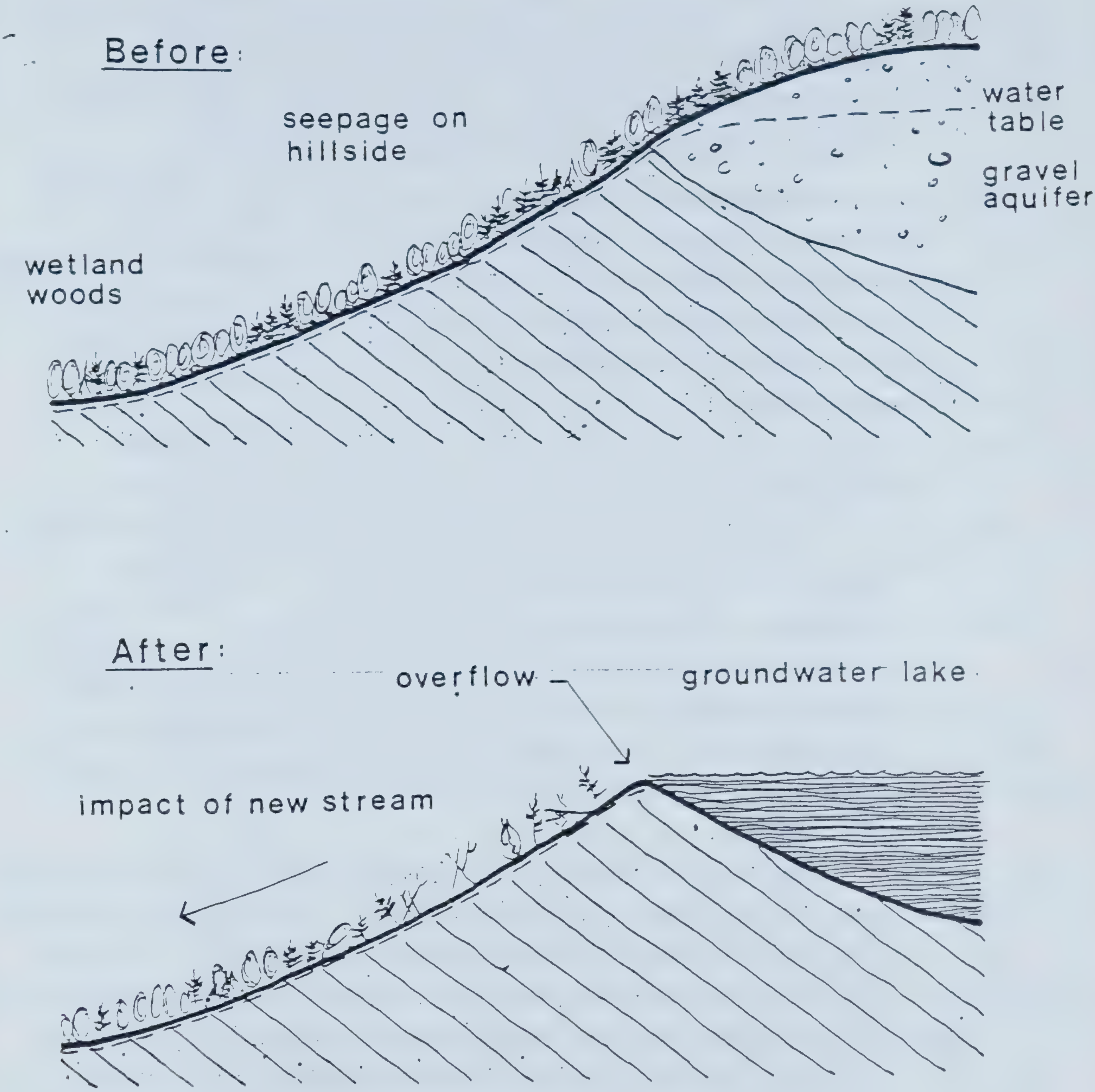


Fig.4: Environmental Conditions Where Mining Creates A New Water Course

the site. Undertaken in a controlled manner, it may provide an opportunity to lower the water level in the lake to facilitate deeper extraction. One advantage of the planning program is that this situation has been recognized.

Environmental considerations such as these should not be addressed on an ad hoc, site by site basis, in which the cummulative impact of mining may not be recognized. By examining the problem from a regional perspective, it is possible to systematically identify potential conflict situations before they arise.

4.3 Control of the Relationship Between Mining and Adjoining Land Uses

The relationship of the aggregate deposit to the existing pattern of the land use and land ownership is also very important. There are two key considerations. First, mining should not be allowed to have a negative impact on adjoining property currently used for other purposes. Secondly, land uses which would be sensitive to the impact of mining should not be allowed on or near areas where excavation will occur in the future.

The impact of mining can be greatly reduced by establishing proper setback distances from property boundaries, and requiring operators to build landscape berms or tree screens. Planning for excavation at a regional level allows systematic identification of all locations where conflicts between mining and existing adjoining uses will occur. This information can be applied by the regulatory agency in granting conditional approvals for mining. For example, mining may be allowed on condition that an undisturbed buffer zone be retained adjoining the property boundary. Encroachment of excavation into this buffer zone may only be allowed when the proponent establishes a landscaped berm of prescribed dimensions. Progressive rehabilitation in

sensitive zones may be subject to time limitations (i.e. rehabilitation completed within one season). In locations where existing land uses are particularly sensitive to the impact of mining, the regional plan provides an objective rationale for refusing any proposals to open a new surface mine.

While the rights of existing land users must be protected, planning for gravel excavation in a region should also provide a regulatory authority with information necessary to control the development of new land uses. For example, a residential subdivision should not be allowed on or near an area where future mining is expected. Once the extent of the aggregate reserve is identified, the regulatory authority has a rational basis for allowing or disallowing development or land subdivision proposals. The policies and criteria can be formally incorporated in municipal planning instruments.

Planning for mine excavation at the regional level allows systematic identification of any locations where it may be advantageous to relocate public roadways or other facilities. The quantity of gravel underlying a road right-of-way, and its associated setback zone, can be significant. Where mining occurs on either side, such a road takes the form of an obtrusive ridge, possibly disrupting the rehabilitation potential on both properties. Relocation of these roads, or replacement at the excavated grade level should be considered an opportunity by public officials to generate revenue or obtain other concessions. The timing may be staged to coincide with major upgrading requirements.

4.4 Standards for Rehabilitation: Setting the Form

Each individual pit owner is expected to rehabilitate his property in a manner which fits the overall mosaic. It is therefore to his advantage in preparing an individual site plan to have some guidance regarding the expectations of any regulatory agency, and the activities on adjoining property.

There is an onus on the regulatory agency to establish and make public the criteria which will be used in evaluating the acceptability of rehabilitation proposals. Planning for excavation and rehabilitation at the regional level should be directed to establish performance standards, as well as guidelines on how to achieve these standards.

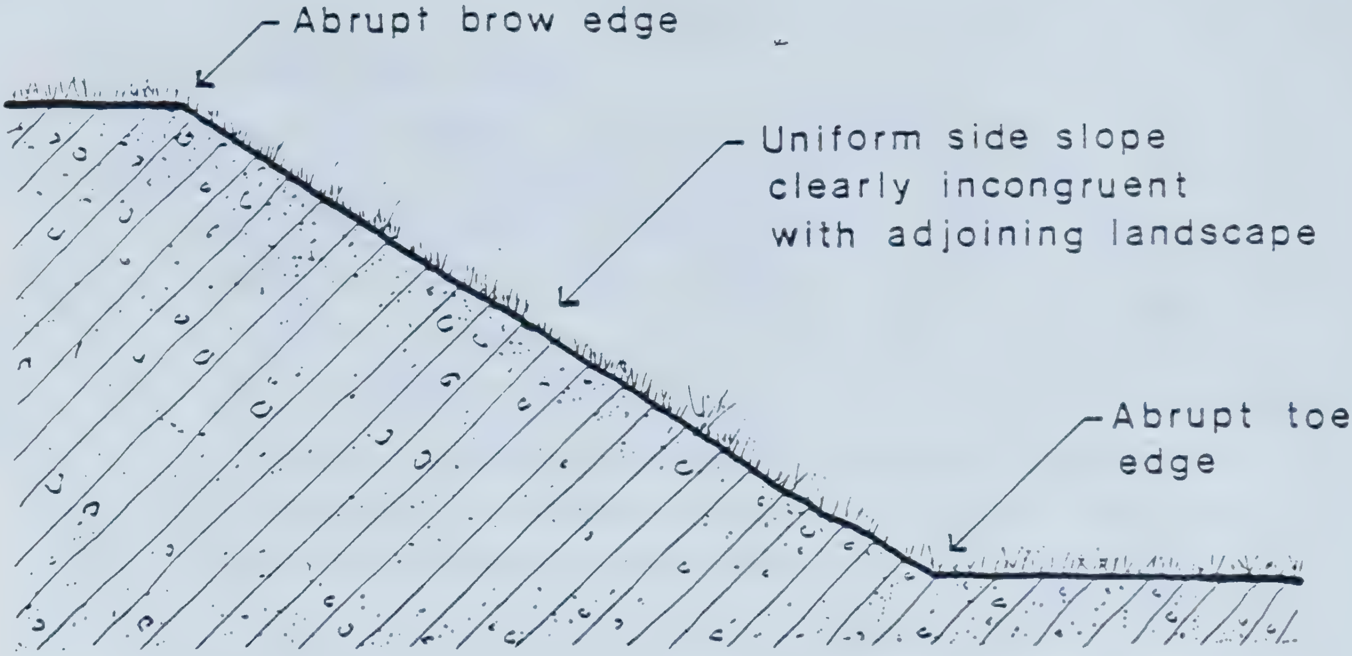
As a minimum, it is expected that the mine landscape will be rehabilitated to a form which is safe, stable, and compatible with adjoining property. Consistent with this, it is commonly accepted that the landscape should sustain at least a minimum level of biological activity and should serve some social or economic purpose.

What criteria will be used to determine compliance with these broad objectives? Stabilization, for example, implies that certain slope and revegetation conditions will be met. Performance standards may set minimum gradients, necessary topsoil conditions, as well as the composition and density of vegetation. Guidance can be provided on what species should be used in various circumstances, as well as the rates of seeding and fertilizer application.

Measures to provide for public safety may involve the prevention of inadvertent access to any dangerous site or the sloping of a shore zone to provide egress.

Aesthetic considerations may include the 'rounding' off of slopes to avoid an artificial configuration (Figure 5). Specifications for tree screens or berms can be prescribed.

Standards regarding the configuration of lakes, particularly the shore zone, may be applied to promote biological activity (Figure 6 and 7) or prevent shoreline erosion problems.



"Artificial" Slope

"Natural" Slope

Fig. 5 : Slope Form

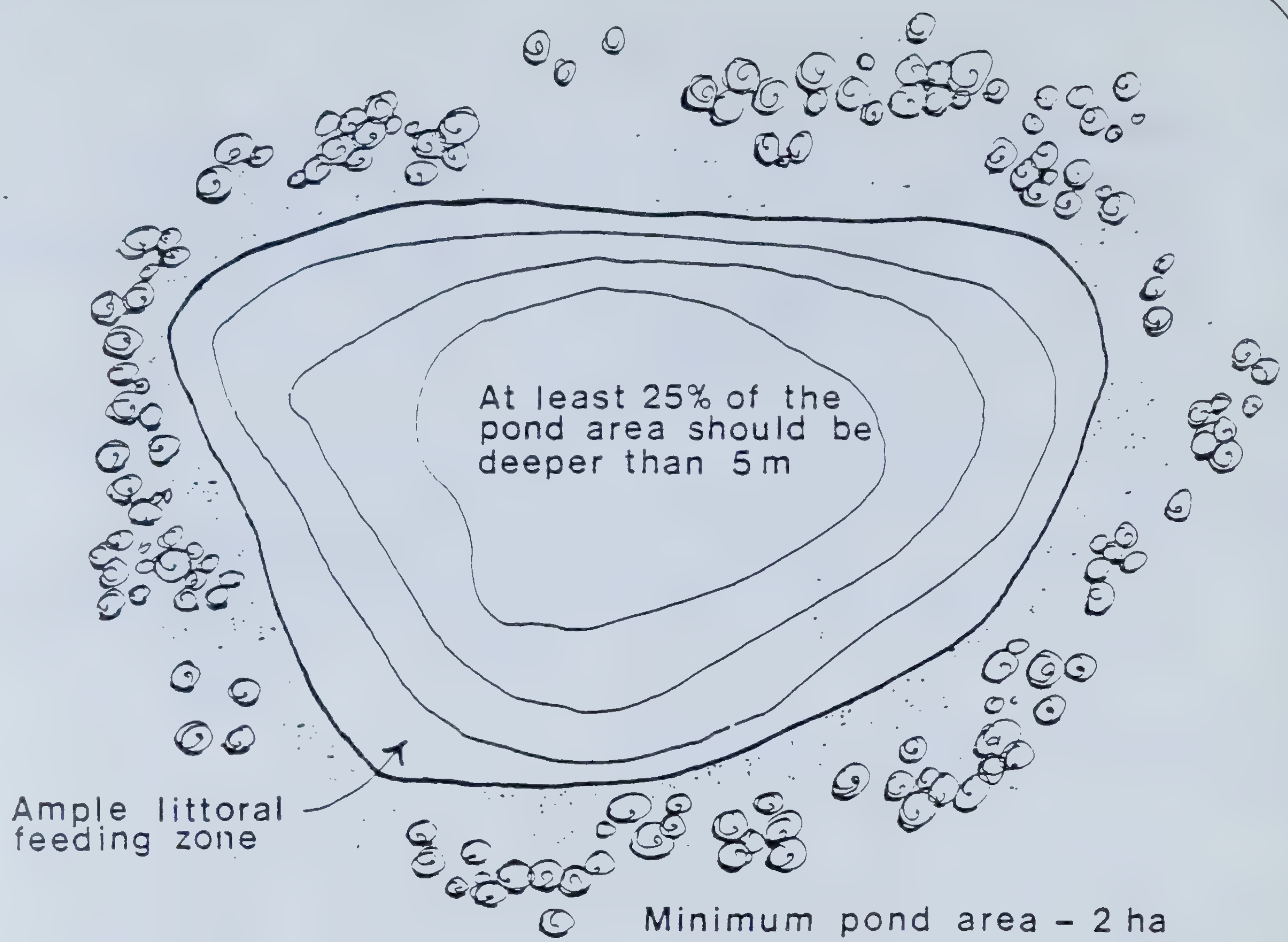


Fig. 6 : Criteria For Fish Stocking

Fig. 7 : Optimum Depths For Duck Habitat

4.5 Development of Post-Mining Land Use Activities

A major consideration in setting the form of a post-mining landscape is the anticipated land use activity to be developed. Rehabilitation planning at a regional level should be directed to establish performance standards related to end use. The scope of concern here will depend on property ownership.

Where the property is owned by the Crown, there is a responsibility on the part of the regulatory agency itself to identify appropriate end land uses.

This will initially involve a regional analysis and feasibility evaluation, leading to generation of alternative concept plans. Factors to consider in weighing feasibility include:

i) Environmental Conditions - the physical requirements of the land use relative to the physical characteristic of the site. (For example, each land use is limited to a specific range of slope gradients).

ii) Regional demand for such a land use.

iii) Availability of alternative sites offering equal or greater advantage.

Once an overall concept plan has been agreed upon, it can be expanded into a rehabilitation strategy which sets development criteria for individual sites, depending on their function. Factors can include minimum slopes, terrain regularity, critical elevations, revegetation requirements, shoreline development, etc. These criteria will have implications in terms of the pattern of mine operation as well as the stockpiling of overburden, topsoil and reject material. The requirements can be prescribed as a condition of the lease or permit under which the mining activity is authorized.

On privately owned property, the decision to develop any particular land use is made by the owner, and will generally be based on economic considerations. The role of a municipal or provincial agency in such planning shifts to safeguarding or promoting the general public's interest.

Some land uses may be a source of contamination in the post-mining landscape. For example, high density residential development can generate pollution through septic fields or storm water run-off, which may rapidly deteriorate water quality in a groundwater lake. In these circumstances, such a land use should be prohibited, or at least subjected to strict conditions which preclude any potential pollution.

The relationship of post-mining land uses is also important. It may be incompatible for one operator to rehabilitate his property to a residential use, while an adjoining operator plans to rehabilitate for industrial functions. In order to conduct a site planning program, each mine property owner should know how his property will fit within the regional mosaic.

Where rehabilitation is to be conducted on an ongoing basis, it is only fair that the owner has some assurances that the investment he makes to grade the site for development will not be lost due to subsequent prohibition of that particular land use by government authorities. This concern is often a key factor which discourages an operator from undertaking an ambitious progressive rehabilitation program. The regional rehabilitation strategy should represent a positive commitment by public agencies, and not simply generate minimum standards.

One problem in any consideration of post-mining land use development relates to the timing of excavation. It may not be reasonable to plan in a detailed manner when mine excavation is expected to continue over a very long term, such as 20 or 30

years. Under such circumstances, plans must remain conceptual and flexible. Even if a portion of the area is depleted, it may not be desirable to develop the ultimate end use when that particular activity is sensitive to excavation continuing on adjoining property.

In order to accommodate this problem, it may be advantageous in early stages to rehabilitate the landscape to a form which allows the greatest potential for future land use development. Land use activities which do not require a long term commitment in the landscape (such as agriculture, forestry, or recreation) may be considered during the interim stage, and be phased out later.

4.6 Phasing of Excavation and Rehabilitation

Planning for mine operation and rehabilitation at a regional level allows regulatory authorities to more objectively control the phasing of activities. Three broad goals may be identified:

i) The ongoing environmental impact of the mining operation should be minimized. A corollary of this is that the proportion of land exposed by surface mining should be minimized through ongoing rehabilitation.

ii) The movement of earth material should be minimized, making efficient use of men and machinery.

iii) A phasing plan should facilitate implementation of the development strategy and the ultimate use of the landscape.

The level of control on phasing will depend on the property ownership, and the scope of legal controls in place at the provincial and municipal level. Where the land is owned by the Crown, for example, the provincial agency may be able to strictly limit mining, and only issue lease or permit authorizations

subject to specific conditions. On privately owned property, municipal zoning may be the instrument of control. In Manitoba, for example, mining has been considered a 'conditional use' in municipal zoning bylaws passed under The Planning Act, and allowed subject to specific requirements prescribed by the local elected council.

Exercising controls on the phasing of mining in a region is inevitably a controversial issue. The objective of minimizing the proportion of land exposed by surface mining must be weighed in relation to the demand for aggregate, the economics of mine operation, and the legitimate rights of a property owner. It is usually unfeasible to dictate or accurately predict the rate of mining in an extended time period, since this is a function of market conditions. A regional phasing strategy should therefore focus on setting priorities for excavation and rehabilitation, providing an overall direction. In the Crown region east of Beausejour, for example, there will be an opportunity to relocate a highway which currently lies on the main deposit. High priority is given to mining out an adjoining area on which the road can be rebuilt, prior to the next scheduled road upgrading program.

4.7 Providing a Forum for Informed Discussion

Perhaps the single most important advantage of a cmmprehensive rehabilitation planning program is that it provides a forum for information exchange, informed discussion, and rational decision making.

Surface mining has historically been a source of concern for local residents, and frequently becomes a contentious political issue. Adjoining property owners fear mining will detrimentally affect their rights, and often lack confidence in the ability or willingness of regulatory agencies to control mining. Mine operators, on the other hand are suspicious of the

Post-mining land use development can be planned in the context of other development on adjoining property. There can be assurances from regulatory authorities that incompatible land uses will not be allowed to encroach near existing or future mining areas. Where a firm commitment is made by regulatory agencies to proposed post-mining land uses, the operator will have added incentive to invest equipment time and money in more ambitious progressive rehabilitation programs.

5.0 Conclusion

In order to fully address the land use and environmental conflicts arising in a pit mining region, there is often a need for regulatory authorities to undertake a comprehensive rehabilitation planning program. This paper has broadly outlined the scope of such programs and the potential advantages.

If these advantages are to be fully realized, planning cannot be undertaken as a short term exercise leading to a static 'master plan'. Like all development planning, this is a process. There will inevitably be unknown variables in our understanding of the geology and groundwater, necessitating ongoing monitoring and refinement. Priorities and economic conditions will shift over time. The planning program must be able to accommodate these changes in a manner which is open to the review of all participants. If it lacks this flexibility it will quickly become outdated and lose its essential credibility.

The ongoing nature of such programs makes evaluation of their success or failure difficult. It is suggested, however, that the value of non-renewable aggregate resources, and the problems associated with mining, justify increased formalization of rehabilitation planning programs.

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AN INTEGRATED RECLAMATION MANAGEMENT PLAN
FOR THE
HIGHLAND VALLEY MINING COMPLEX

by

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ABSTRACT

In the Highland Valley, reclamation of large areas of mining disturbance is being undertaken by several mining companies. Methods and objectives for this reclamation are being studied.

Soil and vegetation surveys are used to classify disturbed materials into site types. Site types have characteristic requirements for their reclamation. By integrating site type information, land-use options and reclamation research, reclamation techniques and objectives are proposed for each site type.

This approach is suitable for the design of reclamation programmes for extensive areas when physical conditions are diverse and mining operations complex.

AN INTEGRATED RECLAMATION MANAGEMENT PLAN
FOR THE
HIGHLAND VALLEY MINING COMPLEX

NTRODUCTION

The Highland Valley, in the Southern Interior Region of British Columbia, as the greatest concentration of open-pit hardrock mines in Western Canada. The rea was selected by the Reclamation Section of the Ministry of Energy, Mines and etroleum Resources, (M.E.M.P.R.), to be the subject of a study which was undertaken y the author during the summer of 1981. The purpose of the study was to evaluate ethods and objectives for the reclamation of land disturbed by mining activity n the Highland Valley.

This paper describes the study method and presents a summary of its esults.

ATIONALE OF STUDY METHOD

At present, there are three mines operating in the Highland Valley and a fourth is expected to come into production soon (Table 1). Changes in mining technology and fluctuations in the market price for copper make it hard to make accurate, long-term predictions of the output of ore, waste-rock and tailings. As a result, it is difficult to predict what the extent of reclamation will eventually be. The objective of this study was to assess areas to be reclaimed, as shown by present conditions, so that prescriptions might be made for the future.

NAME & OWNERSHIP	OPERATING PERIOD beg.	end	PRODUCT	VOLUME TONS/DAY of mill thru'put	AREA DISTURBED to date has.	AREA RECLAIMED to date has.	TOTAL ANTICIPATED DISTURBANCE has.	ELEVATION OF DISTURBED AREAS m a.s.l.
BETHLEHEM -COMINCO	1962	198-	Cu & Mo	20,500	878.9	22	932	1200 - 1550
HIGHMONT -TECK CORPN.	1981	?	Cu & Mo	25,000	976	14	1160	1450 - 1900
LORNEX -member of Rio Algom/ Rio Tinto Corpn.	1972	1993?	Cu & Mo	85,000	1341	221	3280 + 1820	1200 - 1550 1300 - 1400 *
VALLEY COPPER - COMINCO	?	?+20?	Cu & Mo	100,000	384 exploration	—	+ 750	1160 - 1370

* tailings disposal area jointly operated

TABLE 1. Current Status of Mines in the Highland Valley (Reclamation Reports, various dates)

Disturbed areas were to be classified into reclamation site types. Each reclamation site type would describe areas of disturbed materials that presented similar conditions for plant establishment and growth and had characteristic reclamation requirements. (See Fig. 1). This classification scheme would be used:-

1) to acquire more information about the problems associated with each reclamation site type;

2) to select reclamation techniques for each reclamation site type, based on results of reclamation trials carried out by mining companies in the Highland Valley and other reclamation research;

3) to identify "problem site types" where further reclamation research should be directed;

4) to propose land-use objectives for each reclamation site type using the distribution of natural vegetation in the area as an indication of "what grows where".

It could also be used to facilitate prediction of the results of reclamation of the Highland Valley, whatever the size of the area that will eventually be reclaimed.

PROPOSED CLASSIFICATION SCHEME

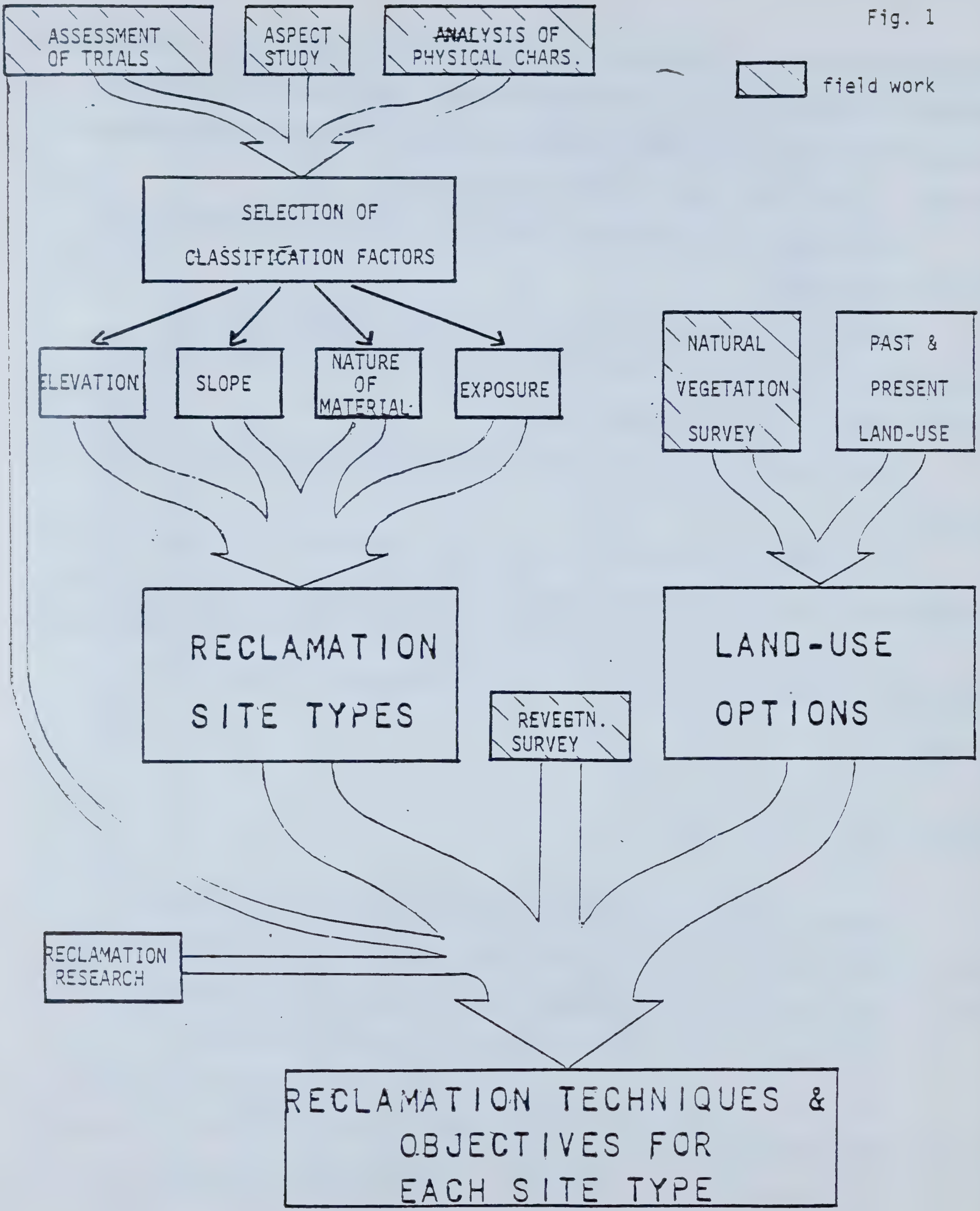
Numerous methods of classifying land are described in the literature (Hills, 1961; Krajina, 1965; Environment Canada, 1970). To fulfill the objectives of this study, the classification scheme had to fulfill three requirements:-

1) it had to be at a scale suitable for management purposes;

2) it had to be based on information that could be acquired from the available maps and aerial photographs of the area;

3) it could not incorporate natural vegetation as a factor since it

Fig. 1


ASSESSMENT OF TRIALS
ASPECT STUDY
ANALYSIS OF PHYSICAL CHARS.
field work
SELECTION OF CLASSIFICATION FACTORS
ELEVATION
SLOPE
NATURE OF MATERIAL
EXPOSURE
NATURAL VEGETATION SURVEY
PAST & PRESENT LAND-USE
RECLAMATION SITE TYPES
REVEGTN. SURVEY
LAND-USE OPTIONS
RECLAMATION RESEARCH
RECLAMATION TECHNIQUES & OBJECTIVES FOR EACH SITE TYPE

was to be applied to areas denuded of natural vegetation.

Review of Hills' method of classification indicated that disturbed areas in the Highland Valley might be classified according to the following factors:-

-elevation,

-aspect,

-physical properties of material,

-slope.

These factors were selected on the assumption that local climate and the retention of moisture in the soil would be the most important factors affecting plant establishment and growth. Slope and physical properties also affect the stability of disturbed areas; reclamation techniques may therefore be modified by the need to control erosion and by constraints on the operation of machinery.

Aspect was selected as a factor in the proposed classification scheme because it is commonly assumed to affect local climate and soil moisture content. However, in semi-arid areas differences due to aspect may not be significant (Clark, 1969). At the Bethlehem mine, shelter from prevailing winds affects the success of reclamation (Walmsley, 1977). In the Highland Valley, prevailing winds are from the south-west.

Chemical properties of materials (pH, available nutrients, etc.) were not included because:-

1) research by Lornex Mining Corporation (1973; undated), Dept. of Soil Science (1975; 1976-77) and Valley Copper Mines Ltd. (1980) on disturbed materials in the Highland Valley has shown that levels of available nutrients are generally limiting to plant growth;

2) fertilization has been required wherever seeding has taken place. Slope and physical characteristics have an effect on the retention of fertilizer in disturbed materials and therefore on their artificially-created chemical

characteristics.

3) chemical characteristics are not readily identified from maps or aerial photographs.

An additional factor, "visibility from public areas", may be incorporated into the classification scheme. This factor is the subject of another study, the results of which will be published at a later date.

PRE-FIELD WORK

Information on elevation and slope of disturbed materials was obtained from maps and aerial photographs.

Disturbed materials could not be classified immediately according to their physical characteristics since this information could not be obtained from maps or aerial photographs. They were initially grouped according to differences in appearance on aerial photographs. Seven kinds of disturbed material could be distinguished:-

1) areas of glacial till whose natural soil covering had been removed,
2) free-dumped waste-rock piles,
3) compacted waste-rock dumps,
4) areas of end-dumped waste-rock,
5) tailings areas,
6) access roads,
7) plant sites and machinery dumps,
8) stock-piled overburden.

End-dumped waste-rock will probably not remain after mining operations end (Munroe, 1981). Access roads will not be reclaimed (Highmont Operating Corporation, 1980) or will be ripped (Valley Copper Corporation, 1980). They and the plant sites,

once cleared, will probably revert to a condition similar to the compacted waste-rock dumps or areas of glacial till. Free-dumped waste-rock piles may be covered with a thin layer of overburden as part of the reclamation operation.

Therefore, four kinds of disturbed materials were selected for field investigation:-

1) glacial till lacking a natural soil covering (referred to hereafter as "raw till"),

2) waste-rock piles covered with overburden ("overburden/rock"),

3) compacted waste-rock ("compacted rock"),

4) tailings.

The distribution of natural vegetation communities was interpreted from aerial photographs and marked on transparencies. Results of a previous vegetation survey of the area (B.C.Research, 1971) assisted in the preliminary identification of communities.

FIELD WORK

a) Identification of each kind of disturbed material was checked in the field and samples were taken for the determination of physical properties in the laboratory.
b) Differences in the temperature and moisture content of disturbed materials associated with differences in aspect were investigated. However, a detailed account of this investigation is outside the scope of this paper. It will be reported at a later date.
c) All accessible reclaimed sites were assessed using the reclamation inventory method (M.E.M.P.R., undated). These sites were, for example, driveways, pipelines, test plots and "final configuration" dumps (those where no further dumping will take place).

d) A selection of naturally revegetated areas was surveyed.

e) Interpreted boundaries of natural vegetation communities were ground-truthed. Representative areas were sampled and the vegetation communities found in these areas were described in detail.

LABORATORY WORK

Textural composition of the disturbed materials and soils was determined using the hydrometer method of particle size analysis described by the Dept. of Soil Science (1978).

RESULTS

a) the physical characteristics of disturbed materials:

Results of the determination of physical characteristics of the disturbed materials and natural soils sampled are summarized as follows:-

1) Raw till and tailings differed significantly in textural composition from each other and from overburden/rock and compacted rock. Raw till contained more sand-sized and less silt-sized particles. Tailings contained no particles greater than 2mm in diameter but were highly variable in composition of particles less than 2mm diameter.

2) No significant differences in textural composition were found between overburden/rock samples and compacted rock samples. (However, since it was not possible to sample more than one area of compacted rock and since rock type varies throughout the Highland Valley, this result should be interpreted with care).

3) Overburden/rock and compacted rock were classed as sandy loam according to the USDA classification system (Brady, 1974). Raw till was classed as sand or loamy sand. Tailings were classed as sandy loam or loamy sand.

4) Natural soils sampled were classed as sandy loam and did not differ significantly in textural composition from overburden/rock or compacted rock samples.

Differences in bulk density between types of disturbed material were not significant.

b) the effect of aspect:

The investigation into the effect of aspect on moisture content and temperature of disturbed materials showed that south-facing slopes were only significantly hotter and drier than north-facing slopes when they were exposed to prevailing winds.

Areas of raw till were significantly drier than overburden/rock areas and compacted rock areas.

c) the assessment of reclaimed areas

Results of the assessment of reclaimed sites are summarized in table 2. All sites were seeded with grass or grass/legume mixes. All sites were within the elevation range 1300-1400m. Details of treatment were very variable but records indicated that all sites had been adequately seeded and maintained with fertilizer. Although differences in length of establishment period, seeding rate and fertilizer treatment must be taken into account, it appears that establishment of grass/legume cover has been least successful on exposed, steeply-sloping sites and on a

SITE TYPE	DATE OF ESTABLISHMENT	PERCENT GROUND COVER			
		MIN.	MAX.	MEAN	S.D.
Exposed south-facing slope ; overburden/rock	1970	7	30	21	10.1
Exposed west-facing slope ; overburden/rock	1972 - 1977?	6	35	19	11.7
Sheltered west-facing slope ; overburden/rock	1977	30	50	38	7.5
Flat ; overburden/rock	1977	25	65	38	16.4
Sheltered north-facing slope ; overburden/rock (1)	1972	7	60	34	27.1
Sheltered north-facing slope ; overburden/rock (2)	1972	20	40	32	8.3
Flat ; overburden/rock	1979	25	40	31	5.4
Sheltered north-facing slope ; raw till	?	35	40	24	11.5
Flat ; raw till (irrigated)	?	8	80	59	17.4

TABLE 2. Summary of Results of Assessment of Reclaimed Areas

non-irrigated raw till site.

d) the natural revegetation survey:

The natural revegetation survey indicated that invasion of disturbed sites does occur when there are sources of propagules nearby and when more sheltered micro-sites exist.

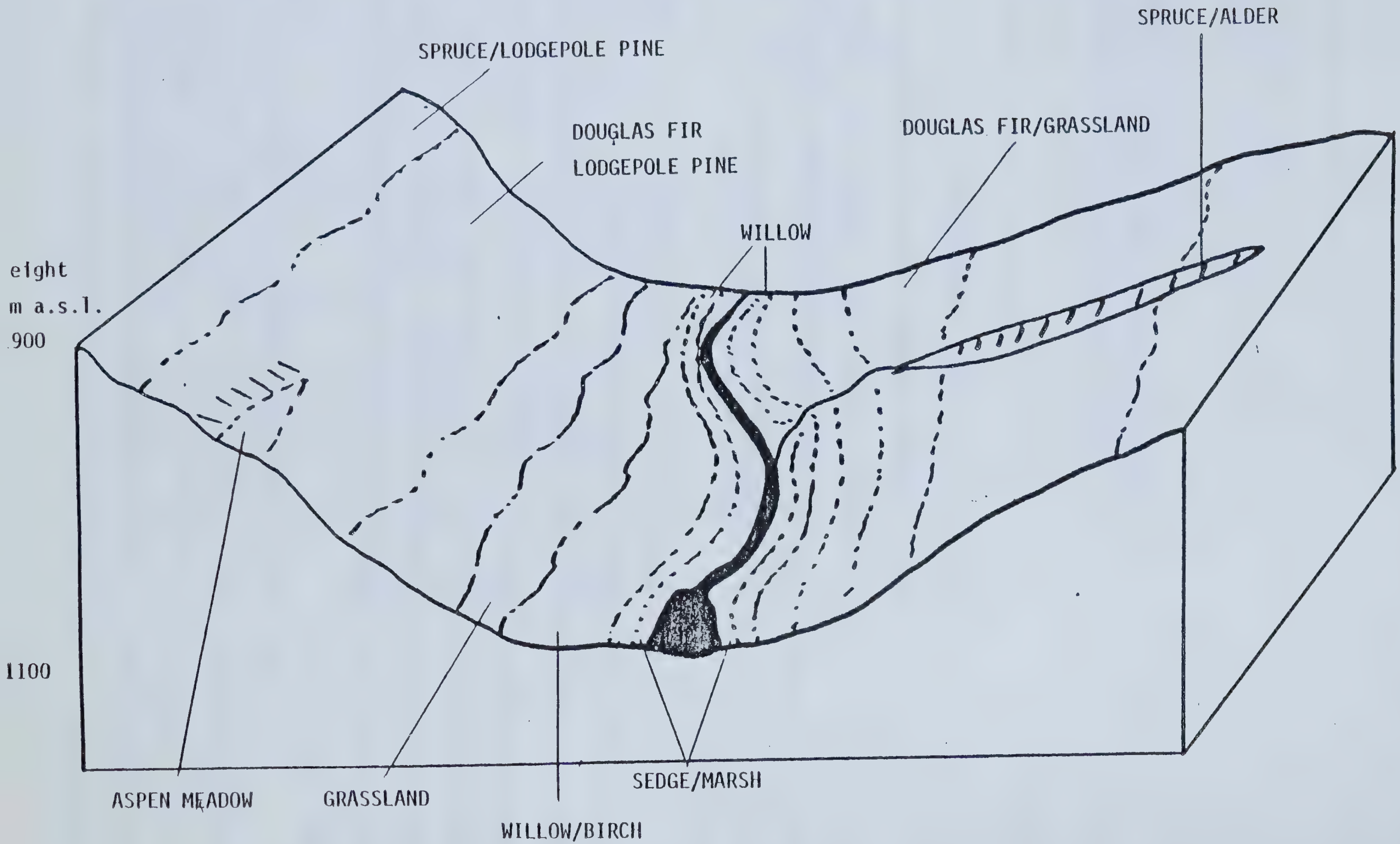
e) the natural vegetation survey and land-use information

During the natural vegetation survey of the Highland Valley, ten natural vegetation communities were distinguished. Community type changes with elevation, topography, local drainage pattern and soil texture The distribution of natural vegetation is illustrated in a generalized cross-section of the Highland Valley (Fig. 1).

The middle slopes of the valley support either Douglas fir communities or, where fire has occurred, lodgepole pine communities. As elevation increases there is a gradual transition to lodgepole pine/spruce communities with spruce becoming increasingly abundant at higher elevations. With decreasing elevation, the forest becomes more open and the lower slopes support Douglas fir/grassland communities. The forest communities are found on sites whose slope varies from 0-38 degrees, (the steepest natural slope found) and on soils with predominantly sandy loam textures.

Two other types of vegetation community are found within the forest area. Spruce/alder communities are located on the edges of creeks draining the valley sides. These areas are poorly drained and have silt and silt loam textured soils. Aspen meadow communities are found on small, almost flat areas with silt loam textured soils. These communities have apparently originated from natural infilling

FIG. 1 GENERALIZED CROSS-SECTIONAL DIAGRAM OF HIGHLAND VALLEY & ITS NATURAL VEGETATION



of bogs and/or small ponds that developed in depressions on the valley sides.

Well-drained areas in the valley bottom support grassland communities These areas are almost flat and have sandy loam textured soils. However, in many parts of the valley bottom, the distribution of vegetation is markedly influenced by the drainage pattern and various stages of hygric succession can be identified. Sedge/marsh communities are found in areas of shallow standing water and are bordered by willow communities. Adjacent areas, with hummock-and-hollow topography and which are less water-logged, support willow-birch communities.

Of the ten natural vegetation communities, two are of commercial significance. The grassland communities provide grazing for cattle. Before mining began, ranching was the major land-use in the Highland Valley.

Some of the Douglas fir communities were commercially logged before mining activity necessitated more widespread clearing of the forest cover. However, almost all the forest sites in the Highland Valley are rated as "poor" (B.C. Forest Service, 1980).

The other vegetation communities found in the Highland Valley are commercially insignificant. The wetland communities are important as habitat for wildlife chiefly deer, moose, elk and waterfowl. Deer, elk and moose, though at present scarce in the Highland Valley because of the mining activity, have in the past used the area for range in the fall and spring (B.C. Fish and Wildlife, 1981). Competition with cattle for grazing has limited wildlife use of the area (B.C. Research, 1971).

No crops are grown in the Highland Valley; this is probably due to the dry climate and the lack of suitable sites, sources of irrigation water and economic incentive.

Fishing is the only important recreational activity, although some hunting is done in the high elevation areas furthest from the centres of mining activity.

DISCUSSION

1. Classification of disturbed areas

The results of the analysis of physical characteristics of disturbed materials, the investigation into the effect of aspect and the assessment of reclaimed sites indicate that disturbed areas in the Highland Valley should be classified according to:-

- -slope,
- -nature of material,
- -exposure to prevailing winds

Elevation should also be included.

Using these factors for classification, eleven reclamation site types can be identified in the area:-

I low elevation tailings
II high elevation tailings
III low elevation flat overburden/rock (and compacted rock?)
IV high elevation flat overburden/rock (and compacted rock?)
V low elevation sheltered steeply-sloping overburden/rock
VI high elevation sheltered steeply-sloping overburden/rock
VII low elevation exposed steeply-sloping overburden/rock
VIII high elevation exposed steeply-sloping overburden/rock
IX low elevation gently-sloping raw till
X high elevation gently-sloping raw till
XI low elevation flat raw till

2. Options for post-mining land-use

When mining has ceased, land-use in the Highland Valley will be determined by the economic climate and the degree of industrial development in the

area. There are, however, a number of land-uses that should be considered now, since choice of an appropriate land-use objective for each reclamation site type has an important bearing on the choice of technique.

Past and present land-uses and the distribution of natural vegetation indicate that the following land-uses should be considered for the Highland Valley.

1) range; this would require the establishment of grass and/or legume swards in areas where cattle access is not restricted. Slopes of 30 degrees or more would be little used by cattle for grazing unless forage was in very short supply (Pitt, 1982). Above 1400m productivity would probably be low.

2) agriculture; flat or gently-sloping low elevation areas, near to sources of water and where the surrounding topography would maximise water retention, could be irrigated and used to grow crops.

3) forestry; flat to steeply-sloping areas from 1200-1700m could be used for forestry. Productivity would probably be low but the eventual value of the crop as well as the aesthetic effect should be taken into account. Natural invasion of areas close to sources of seed would probably occur. More extensive areas would require planting.

4) wildlife; areas supporting grasses and shrubs, particularly those in early seral stages, not used by cattle, would be of particular value to wildlife. Close proximity to forest cover would be an advantage.

5) recreation; well-stocked artificial lakes and ponds would increase the recreational use of this area which is already popular for fishing. The existence of a few roads providing access to both fishing and hunting areas would be advantageous.

3. Proposed reclamation techniques

The combination of information about reclamation site types, natural vegetation, natural revegetation and possible land-use options suggests particular reclamation techniques for each site type. Outlines of these techniques are given here; more details are available.

SITE TYPE I : these could be used for range or agriculture. Research on the potential of tailings for plant growth has been undertaken in the laboratory (Dept. of Soil Science, 1976-77). A large test plot was established on tailings in the Highland Valley in 1981. Creation of wetland communities might be attempted also, although more research into this kind of reclamation is required (Olson, 1981).

SITE TYPE II : it is unlikely that these would be valuable for range or agriculture but they could provide grazing for wildlife. These sites could be reclaimed to a condition similar to the aspen meadow communities. Testing of grass, legume or shrub species suitable for high elevation sites is required, Information acquired in other parts of Western Canada could be applied to this site type.

SITE TYPE III : the feasibility of establishing grass/legume mixtures on these sites has been well proven by the mining companies in the area. These sites may be used for range.

SITE TYPE IV : these sites would have less value for range than type III but could provide for wildlife. Establishment of commercially available legumes at this elevation might be difficult. Trials with "native" species would be informative.

Alternatively, these sites could be managed with a view to establishing

tree and shrub cover. Local lodgepole pine stock and shrubs could be planted with, following or in place of grass/legume cover.

SITE TYPE V : establishment of grass/legume cover on this site type is evidently possible. Though this site type has little potential range value, establishment of cover will increase slope stability and reduce erosion. The appearance of these sites, which are highly visible to the public, would also be improved. If operation of machinery is a problem on these sites they may benefit from treatment similar to site types VII and VIII.

SITE TYPE VI : these sites are similar to site type IV in that modification of the species mix will probably be necessary to ensure successful reclamation.

SITE TYPES VII and VIII : Both these site types pose problems for reclamation. There are two ways of avoiding the problems of applying seed to these exposed sites:-

a) create mini-terraces to provide microsites. This may not be operationally feasible.

b) hand-plant dry-land shrubs. Much research on the use of shrubs for reclamation is being undertaken at present. With emphasis on the selection of species suitable for the climate of the Highland Valley a more intensive approach such as this would probably be justifiable for these particular site types.

SITE TYPE IX: this site type poses slight problems due to the dry conditions which develop. However, many raw till areas are narrow strips resulting from pipeline construction. If a sparse grass and/or legume cover can be established, sufficient to reduce the extreme temperature and moisture conditions, natural invasion by trees and shrubs would likely occur. These sites would then provide wildlife habitat

and eventually become reforested. Complete restocking of these areas may not be desirab if they are to provide access. Extensive raw till areas may require artificial shrub establishment similar to site types VII and VIII.

SITE TYPE X : as with site types IV and VI, the choice of species for this site type is important. On small areas of this site type establishment of grasses and legumes may not be necessary before natural invasion occurs.

SITE TYPE XI : areas of this site type have potential for use as range and, if irrigated, agriculture. Grass and legume establishment is evidently the most appropriat treatment.

CONTINUING WORK

A map and a series of overlays of the Highland Valley are now being prepared at a scale of 1:10,000. These will show:-

1) the present location of areas of each site type and the anticipated location of new areas that will be created at later stages in the mining operations.

2) management areas. In some areas of each site type, proposed reclamation techniques may require some modification to take account of proximity to other site types, access etc.. Management areas will be designated and for each, a reclamation plan (detailing the reclamation techniques to be employed and the timing of the reclamation operations) will be proposed.

3) the anticipated distribution of vegetation and associated land-uses when mining has ceased and reclamation is completed.

CONCLUSIONS

Developing a reclamation plan in this manner accomplishes the following:-

1) makes best use of the knowledge and on-site information acquired by the mining companies in their reclamation activities to date.

2) provides a tool to assist in future reclamation work. Now that the factors that should be used for classification have been selected, the classification scheme can be applied to other areas of disturbance as they are created. It can be used as a means of extrapolating results of trials to other parts of the Highland Valley. The reclamation plans proposed for each management area will assist in planning and budgeting for reclamation staff, equipment and materials.

3) enables assessment of the outcome of reclamation to be made, whatever the extent of the disturbance that eventually occurs. The map and overlays will allow estimation of the acreage of productive land that will be created and will be useful media for communication to the public.

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THE USE OF PLANT SYMBIOSIS FOR LAND RECLAMATION

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ABSTRACT

Most people involved with land reclamation know the interest of using legumes because of their ability to grow without the addition of nitrogen fertilizers. Inoculation of seeds with the proper bacteria (Rhizobium) is normally recommended and easily feasible.

Less people are aware that woody plants such as alders, buffalo berries, sweetferns, etc., are also able to grow without nitrogen fertilizers. Indeed, up to recently, no inocula were available because the cultivation of the causal organisms was not possible. During the last three years, in Quebec province, successful inoculation of 1,200,000 seedlings of alders per year was achieved using laboratory grown pure culture of Frankia. Thus, silky alder (Alnus crispa) has become one of the most important plant for land reclamation in the James Bay area.

Not only nitrogen fixation but also phosphorus mobilisation can be achieved using plant root symbiosis with soil microorganisms. This is indeed possible when soil fungi are associated with roots to form mycorrhizae. Most of the plant species are able to form mycorrhizae with different groups of fungi. The mycorrhizal symbiosis increase by several folds the efficiency of plants to recuperate phosphorus from the soil when it is present in low concentrations. Most soils requiring land reclamation contain very small amount of the proper fungal propagules and therefore require inoculation. Methods for the production of inoculum are now available and industrial inoculum will soon be available. There are indications that some mycorrhizal fungi are able to exclude some elements and therefore might be useful for reclamation on certain toxic materials.

THE USE OF PLANT SYMBIOSIS FOR LAND RECLAMATION

by

J. André FORTIN

1. INTRODUCTION

Life in symbiosis is a fundamental and universally occurring biological phenomenon in plants. Lichens involving species of algae and of fungi are well known for their ability to grow on adverse sites where neither of the associates could survive independently.

For the purpose of revegetation, plant symbiosis occurring at the root level are most usefull. They include two groups of symbionts, the first involving procaryotic microorganisms that give access to the gaseous nitrogen of the air as a source of "mineral" nutrient for the plant (Table 1). The second group involves soil fungi helping the host plants to obtain phosphorus and other nutrients such as zinc and copper from difficulty available sources for the plant let alone (Table 2).

Since nitrogen and phosphorus are two of the major elements that plants require in large quantities, root symbiosis of both types mentioned are usefull for revegetation on nutrient poor sites.

2. THE NITROGEN FIXING ROOT SYMBIOSIS

There are three categories of nitrogen-fixing root symbiosis but only two of them can be used for land reclamation under temperate or cold climates. They involve bacteria of the genus *Rhizobium* or actinomycetes of the genus *Frankia*.

2.1 Nitrogen-fixing root nodules in legumes with *Rhizobium*

All the plants associated with *Rhizobium* belong to the legume family, The most widely used species for revegetation belong to *Coronilla*, *Lotus*, *Melilotus* and *Trifolium* spp.

Most soil encountered in land revegetation are partly or entirely deficient in <u>Rhizobium</u> inoculum unless some top soil is present or added: Therefore application of laboratory grown rhizobial cells is essential if any success is expected in absence of added nitrogen fertilizer.

If nitrogen fertilizer is added instead of rhizobial inoculum the results will be short life and the benefit expected from the legume as a biological source of nitrogen fertilizer will be missed.

The inoculum can be introduced by using <u>Rhizobium</u> coated seeds or by introducing the bacterial cells at time of seedlings. Both forms are available.

Users should remember that these inoculum are living and must be handled accordingly. Care should be exercised when using hydro seeding not to kill the bacteria with high concentrations of fertilizer.

2.2 The use of actinorhizal nitrogen fixing shrubs

Actinorhizal nitrogen-fixing shrubs utilisation is less frequent than that of legumes probably because direct seeding is not possible and also because, up to recently the <u>Frankia</u> inoculum was not commercially available.

<u>Alnus crispa</u> was successfully used in the revegetation of Manicouagan V hydro electric dam building site in Québec. After a slow start of two years, the whole surface was rapidly covered and more than 10 tons/ha dry mass of plant material were produced the third year. This was achieved without any addition of fertilizer or organic matter. After 8 years the alders formed a closed thicket and natural ecological succession is taking place; aspens, birches and firs are coming as undergrowth.

Successful actinorhizal inoculation is necessary to produce seedlings bearing efficient nodules and this was achieved at the industrial scale for the first time in Québec, in 1979, where 200,000 seedlings where inoculated with a pure culture of selected <u>Frankia</u> grown in the laboratory. The inoculum was applied through the irrigation system on container-grown <u>Alnus crispa</u> seedlings produced for the Société d'Energie de la Baie James. The seedlings were outplanted near LG2 dam site. This year 2,160,000 alder seedlings have been successfully inoculated with <u>Frankia</u> industrially produced by Rhizotec Laboratories, a firm located near Québec City.

3. THE MYCORRHIZAL ROOT SYMBIOSIS

Out of the four main categories of mycorrhizae only two will be discussed here. They are the vesicular-arbuscular endomycorrhizae (VAM) and the ectomycorrhizae (ECM). In both cases fungi are involved as indicated by the ethymology (myco= fungus; rhiza= root). VAM ECM are caused by microscopic soil fungi whereas ECM are caused by cap fungi and puff-balls.

As is the case with Rhizobium and Frankia, most soil in need of revegetation lack mycorrhizal inoculum unless some top soil is present or added.

VAM can form on more that 90% of the species of vascular plants including a large number of those currently used for land reclamation.

The causal organisms cannot be cultivated under pure culture conditions and must be propagated on host plants. The first commercially available inoculum in North America was produced in California in 1981 by the nurseryman B. Zuckermann. Biofertec, a Québec firm, is now making this VAM inoculum available for the first time in Canada.

Ectomycorrhizal fungi can also be inoculated on a few species of trees and shrubs such as pine, spruce, fir, birches and alder species.

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TABLE I - NITROGEN FIXING SYMBIOSIS

	Bacteriorhizae	Phycorhizae	Actinorhizae
Microbial symbionts	Bacteria of the genus _Rhizobium_	Blue green algae	Actinomycetes of the genus _Frankia_
Host plants	Exclusive to members of the legume family _Trifolium_, _Lupinus_ _Melilotus_ etc...	A very small number of tropical gymno-sperms of the genera _Zamia_ and _Cycas_	Several woody species of _Alnus_, _Shepherdia_ _Myrica_, etc...
Structure of the microbes	Bacteria in cortical cells transformed into odd shaped bacteroïds	Intracellular algal cells inside cortical cells of the host	Mycelium and septate vesicles within host cortical cells
Structure of the host	Formation of short living root nodules	Dichotomic branching of the roots	Formation of perennial nodules
New function	Nitrogen fixation	Nitrogen fixation	Nitrogen fixation

TABLE 2 - MYCORRHIZAL SYMBIOSIS OF INTEREST FOR LAND RECLAMATIONS

	Vesicular-arbuscular endomycorrhizae	Ericoïd endomycorrhizae	Ectendo-mycorrhizae	Ectomycorrhizae
ungal ymbionts	Endogonaceae, Gigaspora, Glomus, Acaulospora Sclerocystis etc.	Pezizella spp Clavauia spp (?)	Complexipes moniliformis	Truffles, Cap fungi and puff bal
ost plant	More than 90% of the vascular plants	Calluna, Erica Rhododendron and Vaccinium spp	Pinus spp	Woody plants only Pinus, Picea Alnus, Betula spp etc.
ungal tructure	Mycelium, vesicle, arbuscules in cortical cells	coiled hyphae in cortical cells	Hartig net and intracellular penetrations thin mantle	Hartig net, intracellula hyphae, thic mantle
łost structure	No visible morphological changes	No visible morphological changes	Moderate swelling of the roots. Dichotomic forking of roots	Swelling of roots. Dicho mic forking the roots in pines
Improved or acquired physiological properties	Largely improved accumulation of phosphorus, resistance to drought Morphological and phenological changes	Access to tied up organic nitrogen and phosphorus in peat. Exclusion of toxic elements Cu, Zn etc.	Apparently the same as in ectomycorrhizae	Improved abs tion of phos rus. Protect against dise

MICROBIOLOGICAL EVALUATION OF LEGUME INOCULANTS FOR OIL SANDS RECLAMATION

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MICROBIOLOGICAL EVALUATION OF LEGUME INOCULANTS FOR OIL SANDS RECLAMATION

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ABSTRACT

A major problem in the reclamation of tailings sand and mine spoils in Athabasca oil sands surface mining is the development of soil fertility. The plant nutrient concentration in these materials is extremely low. Legumes are an important component of successful revegetation because of their ability to fix atmospheric nitrogen and therefore improve soil fertility. The main purpose of this study, which was initiated in 1978, is to identify and develop ways of improving legume performance. The study involved the isolation of 126 strains of *Rhizobium meliloti* from alfalfa ans sweet clover plants growing in the Syncrude Mildred Lake project area. After a comparison of each strain's infectivity and effectivity on Alfalfa, 12 "best" strains was compared with isolates from a commercial inoculant and with some other known strains of *R. meliloti*. All of the 12 "best" strains were well above average performance while the commercial inoculant was below average performance. A Syncrude (SYN) inoculant was prepared by mixing 3 "best" strains. In subsequent pot trials, alfalfa growth and competition with grass was best when it was inoculated, especially at lower nitrogen fertilizer application rates. A field trial has been conducted to compare the Syncrude inoculant with two commercial alfalfa inoculants on the tailings pond dyke. The plant growth will determine whether the locally isolated rhizobia will be more adjusted to the prevalent environmental conditions and therefore will perform better than commercial inoculant strains.

1. INTRODUCTION

The major oil sands deposits in northern Alberta are the Athabasca, Cold Lake and Peace River oil sands deposits. At present active extraction facilities are located only in the Athabasca deposit. Of the approximately 300 billion barrels considered recoverable from the Athabasca deposit, about 28% is suitable for recovery by surface mining techniques. Both the Syncrude Canada Ltd. and the Suncor Ltd. extraction plants are

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currently using surface mining in the Athabasca deposit. These plants have a combined production of approximately 194,000 barrels per day.

Revegetation of tailings sand is one of the major reclamation problems for Athabasca oil Sands mining plants. The fertility of this material is extremely low (Takyi *et al*, 1977).

Legumes, because of their ability to fix nitrogen and thereby colonize poor soils, are a natural choice for the early stages of the revegetation of mine spoils and tailings sand. However, legumes are only valuable if they possess their appropriate strain of *Rhizobium*. In mine spoils and tailings sand the appropriate *Rhizobium* may not be present, or there may only be strains inefficient at fixing nitrogen. Therefore, the seed should be inoculated with the correct *Rhizobium* culture (Bradshaw and Chadwick, 1980).

Legume inoculants are available commercially but are mainly produced for use in agricultural soils in the United States. Canadian soils and climate conditions vary from those of our southern neighbors. The commercial inoculants which are presently available may not be the most appropriate inoculants for Canadian conditions. Furthermore, these inoculants are developed for use with agricultural cultivars which are not necessarily the best cultivars to use for revegetation in mine spoils and tailings sand. Therefore, there may be a need for the selection of *Rhizobium* strains more suited to the Athabasca oil sand region. The main objective of this study was to develop an inoculant that would enhance legume performance in oil sands reclamation.

2. COLLECTION AND ISOLATION OF *Rhizobium* STRAINS

Both alfalfa (*Medicago sativa*) and sweet clovers (*Melilotus alba* and *M. officinalis*) were sampled in the Syncrude Mildred Lake project area on June 26 - 27, 1979. Only the plants that appeared to be growing vigorously were selected. All plants, cultures and materials were stored at $4^{\circ}C$ to maintain optimal viability.

2.1 Sample Separation and *Rhizobium* Isolation

In the laboratory each plant was identified as one sample. Several pink nodules from each plant were removed from the roots and were surface sterilized. The surface sterilized nodules were then crushed with a sterile glass rod and a loopful of the released rhizobial bacteroids and plant cell debris was aseptically streaked onto a plate of yeast extract mannitol agar (YEM) containing congo red. An isolated colony suspected to be *Rhizobium* was transferred to slants containing YEM without congo red. These stock cultures were stored at $4^{\circ}C$. Only one rhizobial isolate was made from each plant originally sampled. Isolation of suspected rhizobia from the plant nodules was very successful with 126 isolates being made.

2.2 Plant Passage

The technique of plant passage was used as the most reliable method of determining the actual identity of the bacteria suspected to be *R. meliloti*. This technique confirmed the infectivity of the isolated rhizobia on the alfalfa seed. The relative effectivity of the nodules was also indicated by the appearance of the plant shoot.

Approximately 15 surface sterilized alfalfa seeds were placed in the top of a plastic growth pouch (Northrup King Co., Minneapolis, Mn.) and 20 mℓ of sterile Trifolium growth base was added to the bottom of the pouch. After 7 days the pouches were inoculated with the bacteria from the preceding section. The inoculum was prepared by suspending the bacterial growth from one of the stock slants in 7 mℓ of distilled water and this was added to the pouch. The nodules and appearance of the alfalfa plants in the growth pouches after 30 days incubation were easily viewed through the plastic pouch. The inoculated plants had a median nodulation frequency of 6 nodules per plant. Uninoculated plants were mostly without nodules. The pouches containing well nodulated plants were split open to expose the plant roots. A number of large pink nodules were removed, surface sterilized and squashed as described in section 2.1. The bacterial and plant debris suspension was streaked on YEM to isolate rhizobial colonies. These plates usually appeared to be pure cultures. Whenever doubt of purity was evident, the isolated colonies were restreaked and reisolated. Again only one isolate was made from each growth pouch. This ensured the derivation of one rhizobial isolate per plant originally sampled in the field. Stock cultures were maintained on YEM slants at $4^{\circ}C$.

A second plant passage was used to determine the nodulation and nitrogen fixation characteristics of each rhizobial isolate from the first plant passage. A slant of each isolate was resuspended in 10 mℓ of 5 mM phosphate buffer, pH 7.0. Two mℓ of suspension was used to inoculate 2 preseeded growth pouches then was serially diluted and plated on YEM to determine the number of rhizobia per mℓ suspension. The YEM plates were incubated for 72 hours at $30^{\circ}C$ then the total plate count was determined. In all cases an excess number of rhizobia were added to the pouches (1.3×10^7 to 1.3×10^8 cells/seed) to ensure optimal nodulation.

2.3 Rhizobial Infectivity and Effectivity

One pouch from the second plant passage of each rhizobial isolate was used for the analysis of rhizobial infectivity after the plants had been grown for 30 days. The pouch was split open and the individual plants were separated carefully. The number of nodules per plant was counted. The median nodulation frequency was calculated. The median value gave a more representative figure for the number of nodules per plant most frequently seen in the pouch and hence was indicative of the inoculant strain infectivity.

Five plants of each rhizobial isolate with a nodulation frequency at or about the median nodulation frequency were selected for measuring rates of acetylene reduction. Rhizobial effectivity was calculated as the nmoles ethylene produced per nodule per hour. Each effectivity estimate was the mean of the results of 5 individual plants.

The second growth pouch from the second plant passage was used to measure the dry weight of the alfalfa shoots and roots. The plants with few effective nodules (uninoculated) were visibly less developed than the well nodulated plants. This was reflected in the ratio of shoots: roots, where the uninoculated plants had a value of 1.0 or less and the inoculated plants had a ratio usually greater than 1.0 and was rarely greater than 2.0.

2.4 Assessment of Strain Similarity

A simple plot of effectivity vs infectivity allowed the strains to be separated according to these attributes (Figure 1). The position of

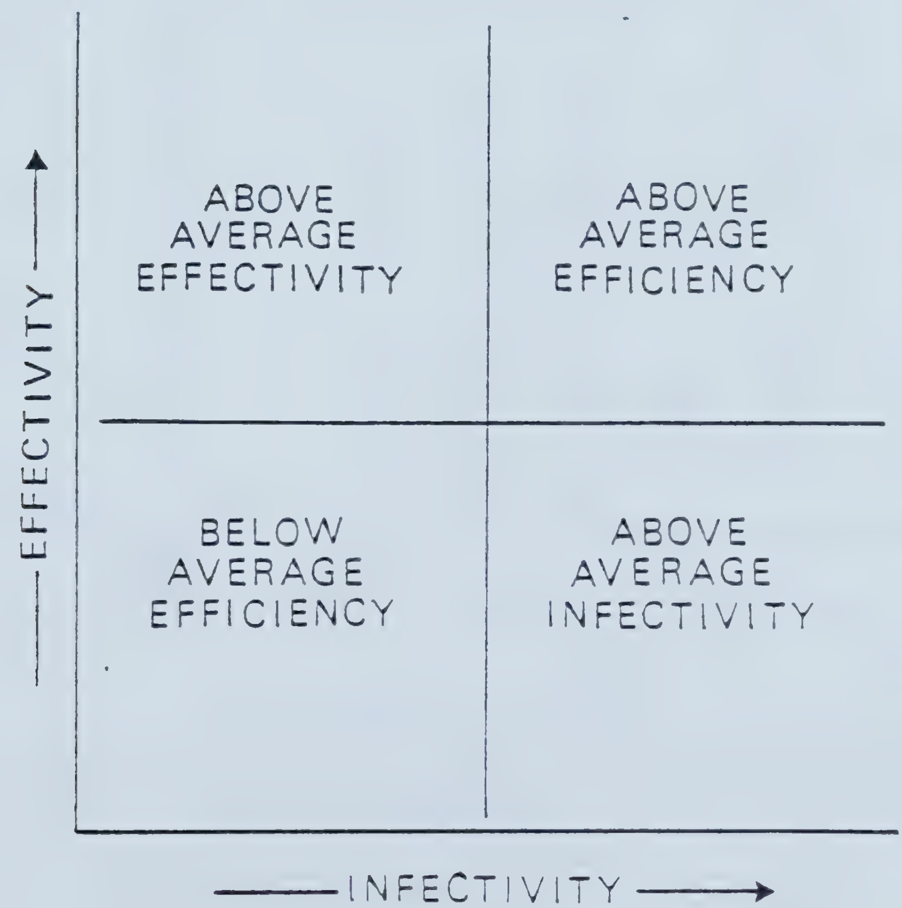

Figure 1. Ideal division of *Rhizobium meliloti* isolate efficiency according to their mean infectivity and mean effectivity.

The dividing axes corresponds to the average effectivity and the average infectivity among the strains. The strains falling into the lower left quadrant would be categorized as having a below average efficiency. The strains in the upper right quadrant would be clearly above average in both effectivity and infectivity, and could be considered to be "best strains". The strains were grouped using the computer program TAXMAP. Each strain was designated as a separate Operational Taxonomic Unit (OTU) described by its attributes of infectivity and effectivity. The program computed the relative proximity between each pair of OTU's then classified the OTU's into relatively isolated subsects of related items (clusters).

A graphic representation of the TAXMAP analysis of the *Rhizobium* strains is shown in Figure 2. All of the isolated strains were

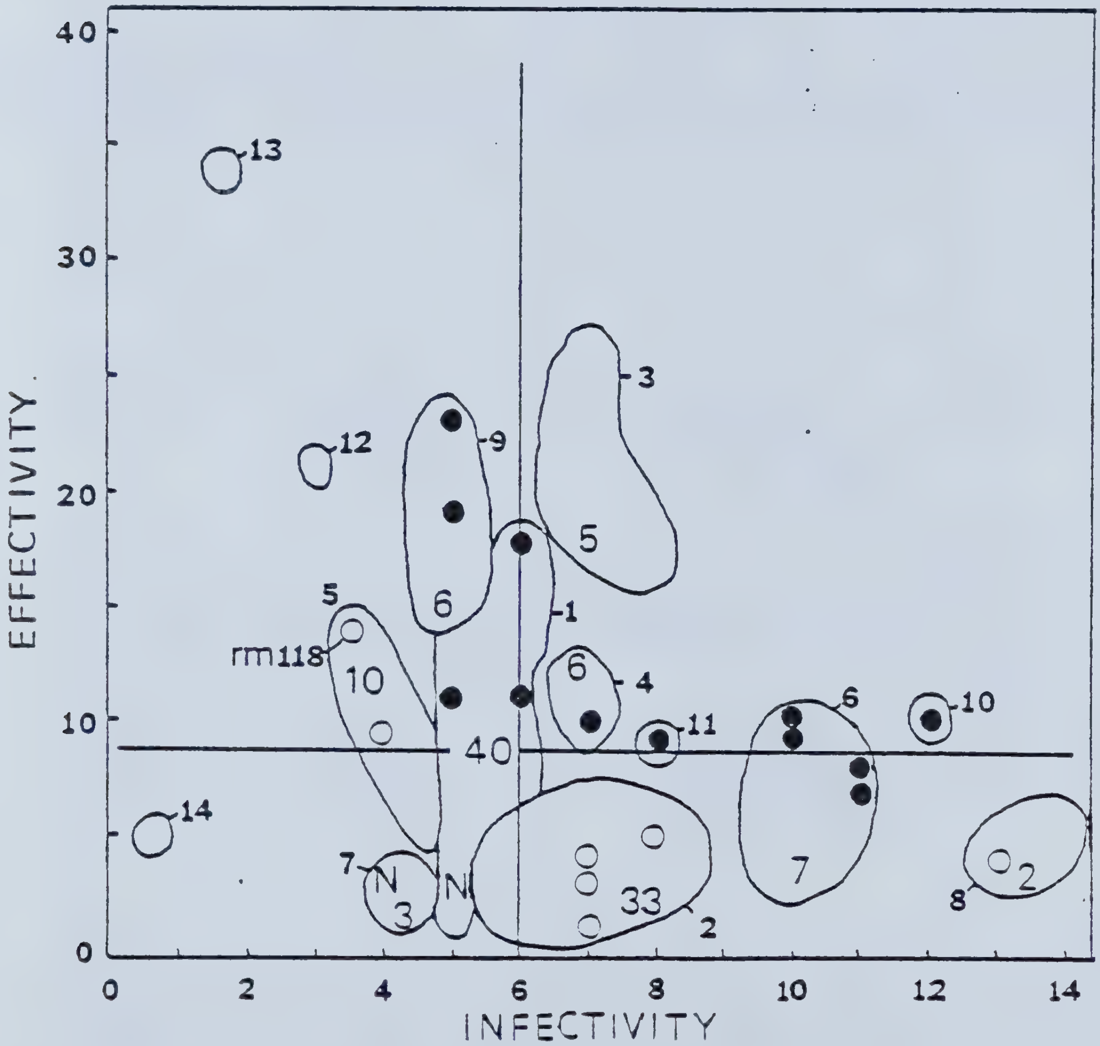

Figure 2. Graphic representation of the clustering of *R. meliloti* isolates according to the TAXMAP analysis. The strains were sorted into 14 clusters (numbers outside clusters). The number inside each cluster is number of isolates found within that cluster, except for clusters 10, 11, 12, 13 and 14 which contained only one isolate. The figure was divided into quadrants according to the criteria used in Figure 1. Above average reliable strains are plotted as the spots within the clusters. The "BEST" isolates are the solid spots within the clusters. Reference strains RM118 and the commercial isolates (N) also are plotted within the appropriate clusters.

grouped into 14 clusters of strongly related strains. Figure 2 shows that strains in clusters 3, 4, 10, and 11 as well as some strains in clusters 6 and 1 had above average performance. The two isolates from the commercial inoculant were both below average in their performance.

2.5 Selection of the "Best" Strains

The strains closest to the dividing axis in Figure 2 were selected as "Best" strains. These strains are marked with solid spots within clusters on Figure 2 and are listed in Table 1. Most of the "Best" isolates were derived when young plants were sampled in the field. Sweet

Table 1. The infectivity and effectivity of 12 selected "Best" *Rhizobium* strains.

Symbiotic Efficiency	Strain Code	Median[1] Nodulation	Average[2] Effectivity	Plant Species
Above Average	2L	7	9.7	Sweet clover
	2V	10	9.8	Alfalfa
	2O	12	10.4	Alfalfa
	2K	6	18.0	Sweet clover
	2B	6	11.3	Alfalfa
	14M	8	8.8	Alfalfa
	14G	10	9.7	Alfalfa
Most Effective	14A	5	11.2	Alfalfa
	17A	5	23.1	Sweet clover
	3C	5	19.1	Sweet clover
Most Infective	3D	11	7.6	Sweet clover
	5F	11	7.3	Alfalfa

[1]Median Nodulation: median number of nodules/plant.
[2]Average Effectivity: nmoles ethylene/nodule/hour.

clover plants yielded more "Best" isolates than alfalfa in this selection. There were 7 "Best" isolates that had above average efficiency (nodulation and nitrogen fixation), 3 "Best" isolates produced less than average nodulation but greater than average nitrogen fixation and 2 "Best" isolates had greater than average nodulation but less than average nitrogen fixation (Table 1).

Commercial inoculants are usually mixtures of strains that have different inoculation abilities in a range of soil conditions. Therefore, a custom-made inoculant should also contain a mixture of strains. This mixture could incorporate some strains with above average nodulation and some with above average nitrogen fixation. A possible mixture of strains would be:

Syn 20	12 nodules/plant	10.4 nmoles ethylene/nodule/hr.
Syn 2K	6 nodules/plant	18.0 nmoles ethylene/nodule/hr.
Syn 17A	5 nodules/plant	23.1 nmoles ethylene/nodule/hr.

This strain mixture was tested in pot studies using a typical soil mixture of tailings sand amended with peat and clay. A commercial inoculant was used for performance comparison.

3. POT TRIALS OF INOCULANT TESTING

The best strain mixture was tested in pot studies using a typical soil mixture of tailings sand amended with peat and clay. The pot trial was set-up to test a number of parameters both individually and together. Basically there were three areas of concern:

- Inoculant: The performance of the Syncrude "Best" isolates were to be compared to the performance of a commercial inoculant. Because commercial inoculants seldom contain a single isolate of *Rhizobium* the SYN strains were therefore tested both individually and as a mixture.

- Nitrogen Fertilizing: The effectivity of nitrogen fixing nodules is normally repressed by ammonia. High soil concentrations of ammonia prevent nodulation and repress the enzymes responsible for nitrogen fixation. A lower soil concentration of ammonia will permit better legume nodulation and nitrogen fixation and will therefore enhance the growth of the legumes and surrounding plants.

- Plant Competition: Legumes will be used in a mixture with grasses for most of the revegetation areas. Therefore, it seems appropriate to test the performance of the *Rhizobium* inoculum on alfalfa when the alfalfa was grown in competition with grass.

3.1 Pot Establishment

The plants were grown in cylindrical plastic bags (disposable plastic petri plate bags) confined within a wooden plywood frame in groups of 9. The bags were filled with the soil mix to a depth of 25 cm. The soils used in this study including tailings sand, peat and clay, were transported from the Syncrude site. The soil was mixed by volume to contain 3 parts peat, 2 parts clay and 1 part tailings sand. The P and K fertilizers were applied at the constant rate of 336 kg/ha of P and 252 kg/ha of K. The nitrogen content of the fertilizer was varied at 224, 168, 112, 56, 28, and 0 kg/ha of N.

The pots were seeded with 6 plants per pot. The seeds were surface sterilized before planting, and allowed to germinate and grow for 3 to 4 days before inoculation in order to optimize root hair development and nodulation by the inoculants.

All *Rhizobium* strains were pregrown on Yeast Extract Mannitol slant. The cells were washed from the slants with 5 mM phosphate buffer, pH 7.2, and the turbidity of the cell suspension was determined spectrophotometrically. The suspensions were diluted and added to the pots to give approximately 10^6 rhizobia/seed. The commercial inoculant was suspended in the same process to obtain an even suspension and was similarly applied to the pots.

The plants were grown in a controlled environment room and were watered with distilled water as required. The plants were harvested after growing two months. The pots were split lengthwise and the plant roots were carefully separated from the soil. The plants were then analysed including length of shoots, length of roots, acetylene-reducing activity, number of nodules and dry weights of shoots and roots.

3.2 Alfalfa Pot Trial

When alfalfa was grown alone in the pots with no brome grass competition there was no significant effect of nitrogen treatment (in the range of 0 - 224 kg/ha), inoculation or inoculum source on alfalfa height, biomass; root length, or nodule number. The plants were equally nodulated and grew equally well in all treatments. However, plants inoculated with the SYN inoculum showed significantly higher effectivity per plant and per nodule at low rates of nitrogen addition (0 - 56 kg/ha) than plants inoculated with the commercial inoculum. At higher nitrogen application rates, effectivity per plant and per nodule were reduced and there were no significant differences between plants inoculated with the different inocula.

Inoculation appeared to affect root development and morphology. Uninoculated plants had approximately 20% of their roots highly branched at the soil surface. When inoculation was applied this surface branching decreased and a greater percent of the plants' roots were evenly branched throughout their length. The SYN mix was more effective than the commercial inoculant in causing this effect.

3.3 Alfalfa - Brome Grass Pot Trial

Significant treatment effects on the growth of alfalfa were observed when the alfalfa was grown in combination with the brome grass. At low nitrogen application rates the alfalfa grew very well and the grass performed poorly. However, the addition of higher concentrations of nitrogen fertilizer shifted the competitive balance in favour of the grass. Therefore, as the rate of nitrogen fertilizer addition was increased the biomass of alfalfa decreased in all inoculum treatments (Figure 3).

The mean number of nodules formed in the alfalfa plants was also affected by the level of nitrogen fertilizer addition. A significant reduction in nodule frequency was observed at higher rates of nitrogen applications (Figure 4). Acetylene reduction assays resulted in an extremely wide range of values, therefore no significant differences could be detected according to inoculum used or N-treatment.

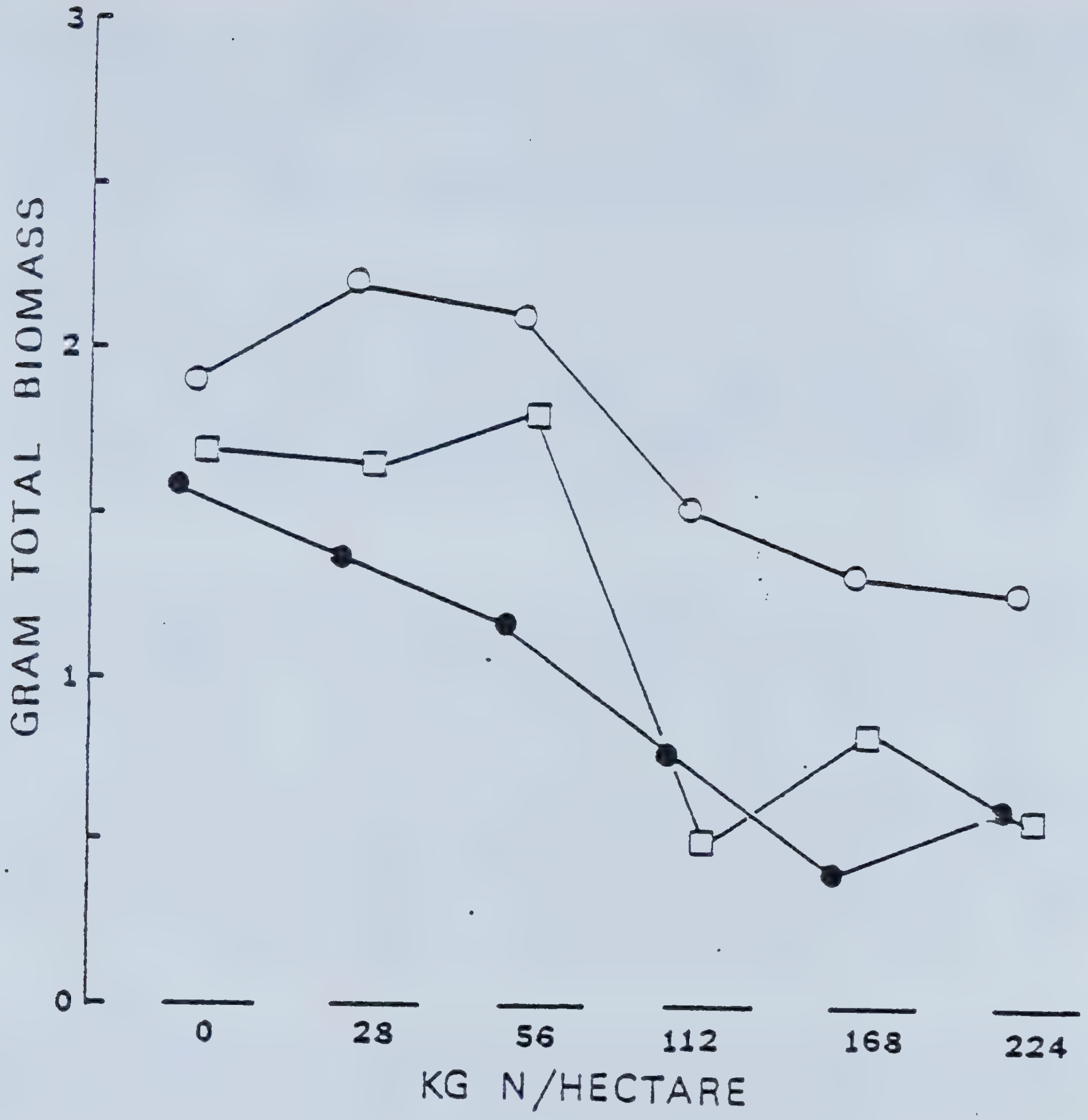

Figure 3. Alfalfa biomass in the alfalfa and grass mixture pot trial The influence of inoculum type : commercial (○), Syncrude mix (□) or uninoculated (●) and the kg N/hectare on the mean biomass of alfalfa is shown.

In this pot trial the alfalfa inoculated with the commercial inoculum performed better at all nitrogen levels than either the uninoculated alfalfa, or the alfalfa which had been inoculated with the SYN inoculum (Figure 3). The alfalfa inoculated with the SYN inoculum did not perform any better than the uninoculated alfalfa.

After two months growth in alfalfa:brome grass pots, the alfalfa plants looked thinner and paler than those in the alfalfa only series. The grass competition was associated with a mottled pattern appearing on the alfalfa leaves in all of the treatments. The uninoculated plants were extremely pale and were loosing leaves. Both alfalfa and grass plants consistently grew best at 28 - 56 kg N/ha when in the presence

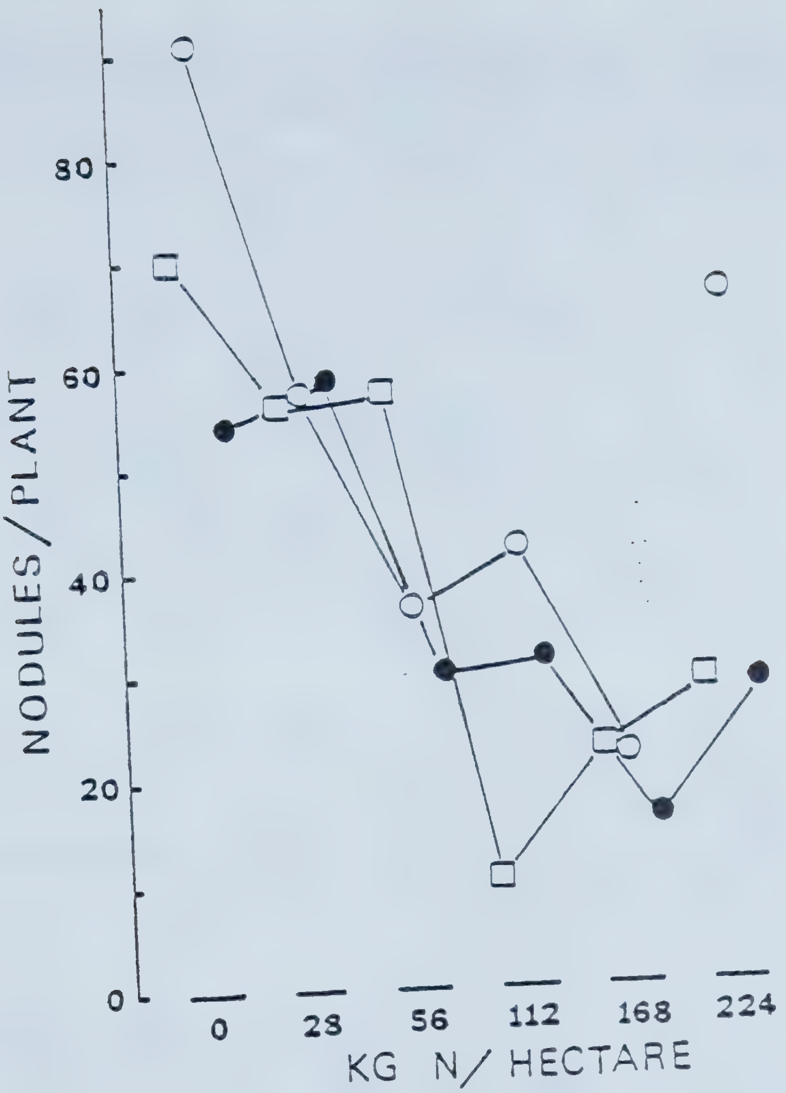

Figure 4. Mean nodules/plant in the alfalfa and grass mixture pot trial. The influence of the inoculant type: commercial (O), Syncrude mix (□) or uninoculated (●) and the kg N/hectare on the mean number of nodules per alfalfa plant is shown.

of inoculated alfalfa. It would appear that in this soil mix the 28-56 kg N/ha range is optimal for the growth and competition of both species.

4. MINIMUM INOCULUM REQUIRED FOR EFFECTIVE NODULATION

The commercial peat-based inoculation procedure may deliver less than the Agriculture Canada recommended minimum of 10^3 rhizobia/seed under certain methods. It was therefore important to determine the minimum level of inoculum required to effectively nodulate the alfalfa in a Syncrude soil mixture.

Duplicate pots containing the Syncrude soil mixture were seeded with 5 alfalfa seeds and were inoculated 4 days later with known levels (standardized by plant counts) of solubilized commercial inoculum or a suspension of the Syncrude (SYN) mixed inoculum. The pots were incubated in the controlled environment room and were watered periodically with

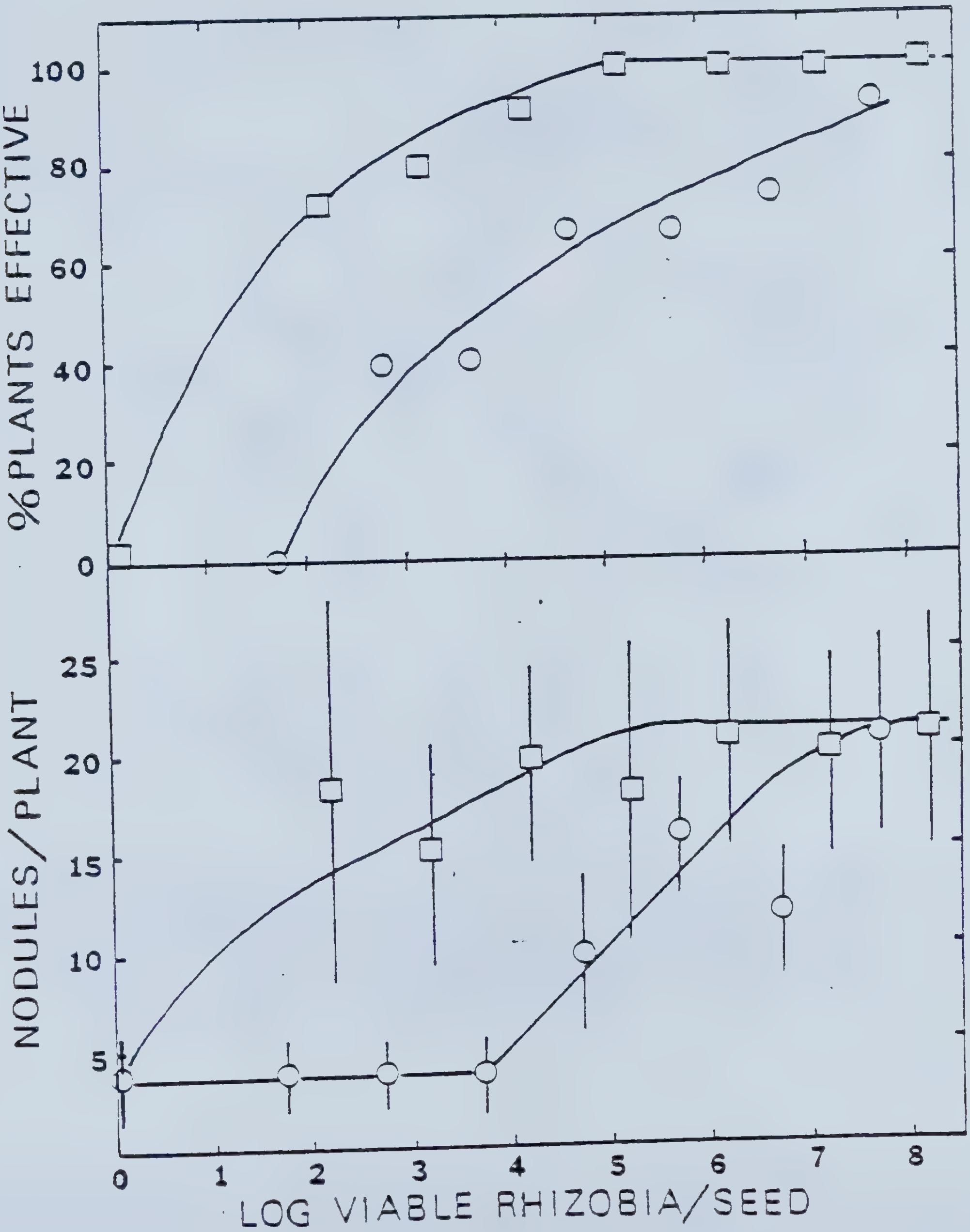

Figure 5. Enhanced nodulation at low level of inoculum. Either the commercial inoculum (o) or the Syncrude mixed inoculum (□) was applied to small pots of alfalfa. The effect on the percent of the plants that were effectively nodulated (acetylene reducing) is shown in A. Part B reports the mean number of nodules per plant plus the 95% confidence levels.

sterile *Trifolium* growth base. After one month of growth the plants were carefully removed from the soil and evaluated for nodulation and acetylene reduction activity.

When a series of plants inoculated with different levels of the commercial and SYN mixed inoculants were examined, the harvested plants showed striking differences in nodulation and effectivity according to the type and amount of inoculum used. As shown in Figure 5A a greater percent of the plants were effectively nodulated with the SYN mixed inoculum than with the commercial inoculum, especially at low inoculum levels. Further examination of the plants (Figure 5B) showed that the SYN mixed inoculum formed more nodules per plant at low inoculum levels than the commercial inoculum. Figure 5 also indicated that the Syncrude soil mixture contained ineffective indigenous *R. meliloti*. These bacteria formed 5 nodules/plant in the uninoculated pots and the nodules were ineffective. As more bacteria were added the effectivity per nodule increased suggesting that either each nodule became more effective or more of the nodules became effective.

The SYN inoculum could be expected to be more effective than the commercial inoculum because the former was selected for nodulation on the alfalfa cultivar grown in local oil sands soils. The enhanced nodulation at low inoculum level may indicate a synergistic effect with the resident ineffective *Rhizobium* population. This explanation is supported by the recent results of Rice and Olsen (1980) in Beaverlodge, Alberta and Rolf *et al* (1980) in Australia who also have observed enhanced nodulation and plant yield with mixed effective and ineffective strains. Our results suggest that this synergistic effect may also include a "helper" effect whereby more nodules are formed at low effective strain inoculum levels. This "helper" effect was only observed when native effective strains (i.e. SYN mix) were combined with the native ineffective rhizobia.

5. SUMMARY

In 1979, *Rhizobium meliloti* strains nodulating alfalfa and sweet clover were isolated from these legumes growing in the Syncrude Mildred Lake project area at Fort McMurray, Alberta. Among 126 isolates established 68% of the isolates were derived from alfalfa nodules and the others were derived from sweet clover nodules. Control strains of *R. meliloti* included 2 isolates from the commercial inoculant.

The symbiotic efficiency of the isolates was analysed by the number of nodules produced per plant (infectivity) and the average nmoles ethylene produced per nodule per hour (effectivity or nitrogen fixation). This allowed the comparison of strains on the same basis. A computer program designed to group taxonomically similar strains was used to cluster the *Rhizobium* isolates. This program grouped the isolates into 14 clusters. There were 77 strains with average or better performance. These strains were further analysed for the reliability of their effectivity value. From these data, 12 "Best" strains were selected that had reliable effectivity estimates. The two strains from the commercial inoculant both plotted in the below average efficiency. Among the 12 "Best" strains, 3 were selected and pooled as the SYN inoculant mix.

This mixture incorporates one strain with above average nodulation and two strains with above average nitrogen fixation.

This strain mixture was further tested in pot studies using a typical soil mixture of tailings sand amended with peat and clay. The commercial inoculant was used for performance comparison. Pot trials were set up to examine the effects of nitrogen fertilization on the growth of inoculated alfalfa grown alone or in competition with brome grass.

The results did not indicate any clear advantage to the use of either the commercial inoculum or the locally isolated SYN inoculum. When alfalfa was grown alone, there was no significant difference between the two inocula. In the pot trial in which the alfalfa was grown in competition with the brome grass, the alfalfa inoculated with the commercial inoculum performed better. However, in a third trial the locally isolated SYN inoculum produced more effective nodules than the commercial inoculum at equivalent inoculum densities.

The results of these laboratory and greenhouse experiments, while not conclusive, have been promising enough to encourage further testing. Consequently, in 1981, a field trial was established on the slope of a tailings sand dyke on the Syncrude lease to evaluate these two inocula as well as two different inoculation techniques, peat-based inoculation and Prillon coated seed inoculation. This field trial should provide better evidence with regard to the relative benefits of using a locally isolated inoculum as compared to a commercial inoculum.

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CHARACTERIZATION AND ENUMERATION OF MICROORGANISMS IN LYSIMETER EXPERIMENTS ON URANIUM MINE MILL WASTES FROM ELLIOT LAKE, ONTARIO

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Abstract

The enumeration of iron-oxidizing thiobacilli in accelerated leaching experiments conducted in lysimeter boxes showed that these bacteria are present at concentrations much greater than in the tailings; this is an indication of the acceleration of pyrite oxidation in the lysimeters. Domestic hypochlorite bleach applied to tailings in a lysimeter at a concentration of 3ml/L, inbibited, but did not entirely eliminate, these bacteria. Characterization and enumeration of microorganisms in untreated and chemically fixed tailings and sediments also conducted in lysimeter boxes showed that a higher level of microbial activity occurred in chemically fixed tailings as compared with the untreated samples. On the other hand chemically fixing the sediments decreased microbial activity.

Characterization and Enumeration of Microorganisms In Lysimeter Experiments On Uranium Mine Mill Wastes From Elliot Lake, Ontario

by

K.C. Ivarson and M.S. Silver

INTRODUCTION

Uranium is extracted from ores of the Elliot Lake region of Ontario by sulfuric acid processes. After treatment with lime, which increases the pH from 6.5 to 9, the slurry (containing calcium sulfate, radium, thorium, residual uranium and 3 to 7% (by weight) pyrite) is deposited in small lakes or swampy depressions; dams consisting of gravel and mine waste rock are used to contain the tailings in these areas. In the presence of dissolved oxygen and iron-oxidizing thiobacilli, the pyrite is oxidized with the formation of sulfuric acid and basic ferric sulfates, having the general formula $AFe_3(SO_4)_2(OH)_6$ in which A may be K^+, Na^+, NH_4^+, H_3O^+, $\frac{1}{2}Pb^{2+}$ or Ag^+.

The main reactions involved can be written as:

$$2FeS_2\,(\text{pyrite}) + 7O_2 + 2H_2O \longrightarrow 2FeSO_4 + 2H_2SO_4 \quad [1]$$

$$4FeSO_4 + 2H_2SO_4 + O_2 \longrightarrow 2Fe_2(SO_4)_3 + 2H_2O \quad [2]$$

$$3Fe_2(SO_4)_3 + 12H_2O \longrightarrow 2AFe_3(SO_4)_2(OH)_6\ (\text{basic ferric sulfate}) + 5H_2SO_4 \quad [3]$$

Equations [1] and [3] are chemical reactions. On the other hand, because the rate of the chemical oxidation of $FeSO_4$ is very slow at pH values <4, while that by *Thiobacillus ferrooxidans* is very rapid, the reaction in Eq. [2] is mainly bacteriological. The large amount of acid produced makes the reaction in Eq. [3] one of the most acidic of weathering reactions.

The ferric iron also can oxidize the residual uranium and other heavy metal minerals from the tailings. When the surface of the tailings are dry, wind erosion causes radionuclide-containing dust. As vegetation of the tailing impoundments is one suggested method of decreasing both the dust and acid generation, CANMET (then the Mines Branch) began, in 1971, a research project which included the vegetation of the mine tailings site. A preliminary assessment of the microbial flora of the tailings surface indicated that sufficient microorganisms were present to allow recycling of plant nutrients. Further investigations revealed the development in the top 5 cm of the vegetated tailings of a microbial population characteristic of a normal soil.

Because the weathering of the tailings is a long-term process, lysimeter boxes were constructed to study first, the effects of accelerated water leaching on uranium tailings and second to characterize and enumerate the microorganisms present in untreated and chemically fixed tailings and sediments.

RESULTS

The enumeration of iron-oxidizing thiobacilli in accelerated leaching experiments (Table 1) showed that these bacteria are present at concentrations much greater than in the tailings (Table 2): this is an indication of the acceleration of pyrite oxidation in the lysimeters. Domestic hypochlorite bleach applied to tailings (Table 3) in a lysimeter at a concentration of 3 ml/L, inhibited, but did not entirely eliminate, these bacteria. Characterization and enumeration of microorganisms in untreated and chemically fixed tailings and sediments (Table 4) showed that a higher level of microbial activity occurred in chemically fixed tailings as compared with the untreated samples. On the other hand, chemically fixing the sediments decreased microbial activity. Similar results were obtained (Figs. 1, 2 & 3) when rates of microbial respiration in presence and absence of added organic matter (glucose) were measured.

TABLE 1

IRON-OXIDIZING BACTERIA CONCENTRATION IN LYSIMETER A (NO BLEACH)

	Depth (cm)	pH	Moisture (%)	Iron-oxidizing bacteria (x 10^5 cells/g)
Hole 1:	0-4	3.62	9.9	160
	4-7	3.77	13.1	54
	7-10	3.16	16.6	10
	10-14	3.50	19.4	21
	14-18	3.92	20.3	37
Hole 2:	0-4	3.88	21.2	10
	4-7	4.11	20.0	12
	7-10	3.95	17.4	25
	10-14	4.06	19.0	52
	14-18	4.23	22.0	25
Hole 3:	0-4	3.92	21.4	295
	4-7	5.10	9.9	>987
	7-10	4.33	20.1	738
	10-14	4.50	17.4	294
	14-18	4.52	16.0	855
Hole 4:	0-4	3.25	12.6	91
	4-7	3.45	16.5	110
	7-10	3.28	20.0	315
	10-14	3.54	22.9	690
	14-18	3.34	25.6	616
Hole 5:	0-4	3.35	23.2	91
	4-7	3.28	21.6	>949
	7-10	3.23	22.0	>894
	10-14	3.24	25.0	>736
	14-18	3.59	27.5	40

TABLE 2

IRON-OXIDIZING BACTERIA FROM CORE SAMPLE

Sample #	Depth (m)	pH	Moisture (%)	Iron-oxidizing Bacteria (cells/g)
1	0.15-0.30	3.72	19.9	0.1
2	0.45-0.60	3.75	19.4	110
3	0.75-0.90	3.28	14.7	32
4	1.05-1.20	3.34	20.2	0.7
5	1.35-1.50	3.58	19.0	<0.1
6	1.65-1.80	3.66	23.3	<0.1
7	1.95-2.10	3.68	26.6	0 ND
8	2.25-2.40	3.89	12.0	0 ND
9	2.55-2.70	3.83	21.1	0 ND
10	2.85-3.00	3.89	24.0	<0.1
11	3.10-3.25	3.87	22.0	1,200
12	3.40-3.55	3.95	23.5	120,000
13	3.70-3.85	4.40	23.7	5,400
14	3.85-4.00	4.02	37.7	26
15	4.00-4.15	4.04	38.9	58
16	4.30-4.45	3.77	45.6	12
17	4.60-4.75	3.69	24.0	30
18	4.90-5.00	3.70	30.4	0.3
19	5.15-5.30	3.70	30.4	0.1
20	5.45-5.60	3.82	29.1	<0.1
21	5.75-5.90	3.76	23.5	<0.1
22	6.00-6.15	4.03	41.9	0 ND
23	6.30-6.45	3.92	55.7	0 ND
24	6.60-6.75	3.60	29.9	<0.1
25	6.90-7.00	4.56	30.2	0 ND
26	7.15-7.30	5.24	40.1	0 ND
27	7.45-7.60	6.31	46.3	<0.1
28	7.75-7.90	7.16	57.2	0 ND
29	8.00-8.15	7.40	66.5	0 ND
30	8.30-8.45	7.40	59.3	0 ND

ND = Not determined

TABLE 3

IRON-OXIDIZING BACTERIA CONCENTRATION IN LYSIMETER C (WITH BLEACH)

	Depth (cm)	pH	Moisture (%)	Iron-oxidizing bacteria (cells/g)
Hole 1:	0-4	5.90	12.1	150
	4-7	6.16	10.9	580
	7-10	4.87	18.8	13
	10-14	4.79	23.5	37
	14-18	5.05	26.6	3
Hole 2:	0-4	1.98	8.4	73,000
	4-7	2.02	11.9	167,000
	7-10	1.95	15.6	214,000
	10-14	1.90	22.1	134,000
	14-18	2.18	27.2	860
Hole 3:	0-4	6.55	6.0	155,000
	4-7	7.48	11.8	290
	7-10	3.54	19.7	3,900
	10-14	4.26	23.7	1,100
	14-18	4.61	23.5	3,600
Hole 4:	0-4	6.75	6.9	76,000
	4-7	3.15	12.0	54,000
	7-10	3.33	18.9	44,000
	10-14	3.74	20.0	1,500
	14-18	4.30	21.0	1,100
Hole 5:	0-4	7.59	8.0	42,000
	4-7	3.33	15.8	39,000
	7-10	3.61	14.9	21,000
	10-14	4.02	22.0	24,000
	14-18	4.29	23.1	34,000

TABLE 4

TOTAL COUNTS OF MICROBIAL POPULATION

Organism	$BaRaSO_4$ Sediments		Tailings: Non-Vegetated		Tailings: Vegetated	
	Non-fix	Chem. fix	Non-fix	Chem. fix	Non-fix	Chem. fix
Bact. + Act.	$1.1x10^5$	$4.0x10^2$	<10	$5.0x10^3$	<10	$8.0x10^6$
Fungi	$2.7x10^2$	<10	<10	<10	$5.0x10^2$	$8.0x10^2$
Aerobic Spore Formers	$2.5x10^4$	<10	<10	$3.5x10^2$	<10	$1.4x10^5$
Anaerobic Spore Formers	$1.1x10^3$	<10	<10	$0.7x10^2$	<10	$1.3x10^2$
Nitrobacter	$1.0x10^2$	<10	<10	<10	<10	$1.0x10^4$
Ammonifiers	$1.0x10^2$	<10	$2.3x10^1$	<10	<10	$1.0x10^3$
Denitrifiers	$1.7x10^5$	$1.0x10^3$	<10	$3.3x10^3$	$1.8x10^5$	$1.6x10^6$
Aerobic N-fixers	$3.0x10^2$	<10	<10	<10	<10	$1.5x10^2$
Anaerobic N-fixers	$7.0x10^2$	<10	<10	<10	<10	$2.3x10^2$
Sulfate Reducers	<10	$2.3x10^2$	<10	<10	<10	$1.0x10^2$
Fe-oxidizers	$7.0x10^3$	$2.0x10^2$	$4.0x10^5$	$3.0x10^2$	$3.0x10^5$	$3.0x10^4$
Aerobic Cellulose Decomposers	$3.5x10^4$	<10	$2.3x10^1$	$1.1x10^2$	$2.0x10^2$	$4.9x10^4$
Anaerobic Cellulose Decomposers	<10	<10	<10	<10	$2.4x10^2$	$6.8x10^2$

Fig. 1. MICROBIAL RESPIRATION IN VEGETATED TAILINGS

B+A = counts of bacteria & actinomycetes after 7 days of incubation
F = counts of fungi after 7 days of incubation

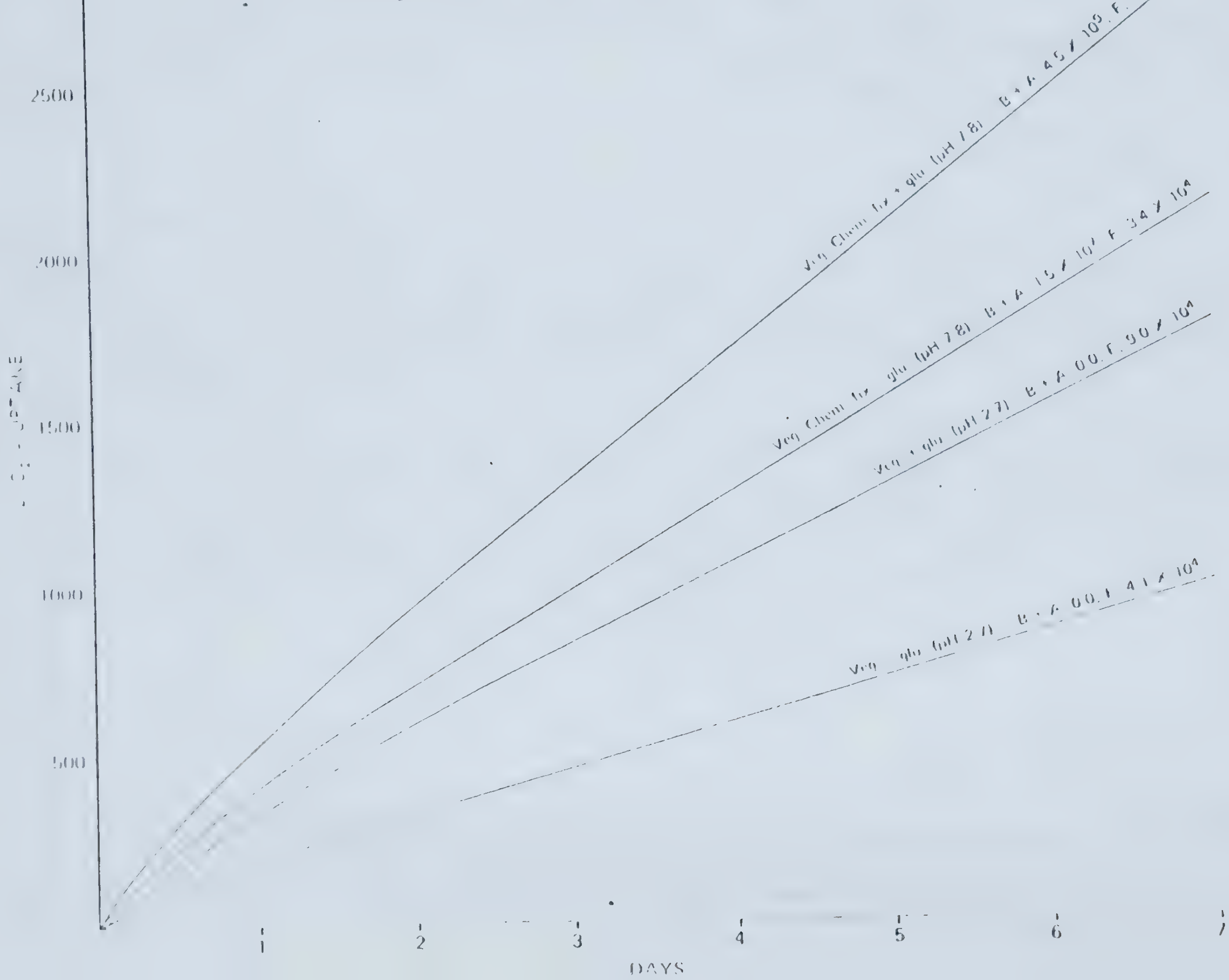

Fig. 2. MICROBIAL RESPIRATION IN NON-VEGETATED TAILINGS

B+A = counts of bacteria & actinomycetes after 7 days of incubation
F = counts of fungi after 7 days of incubation

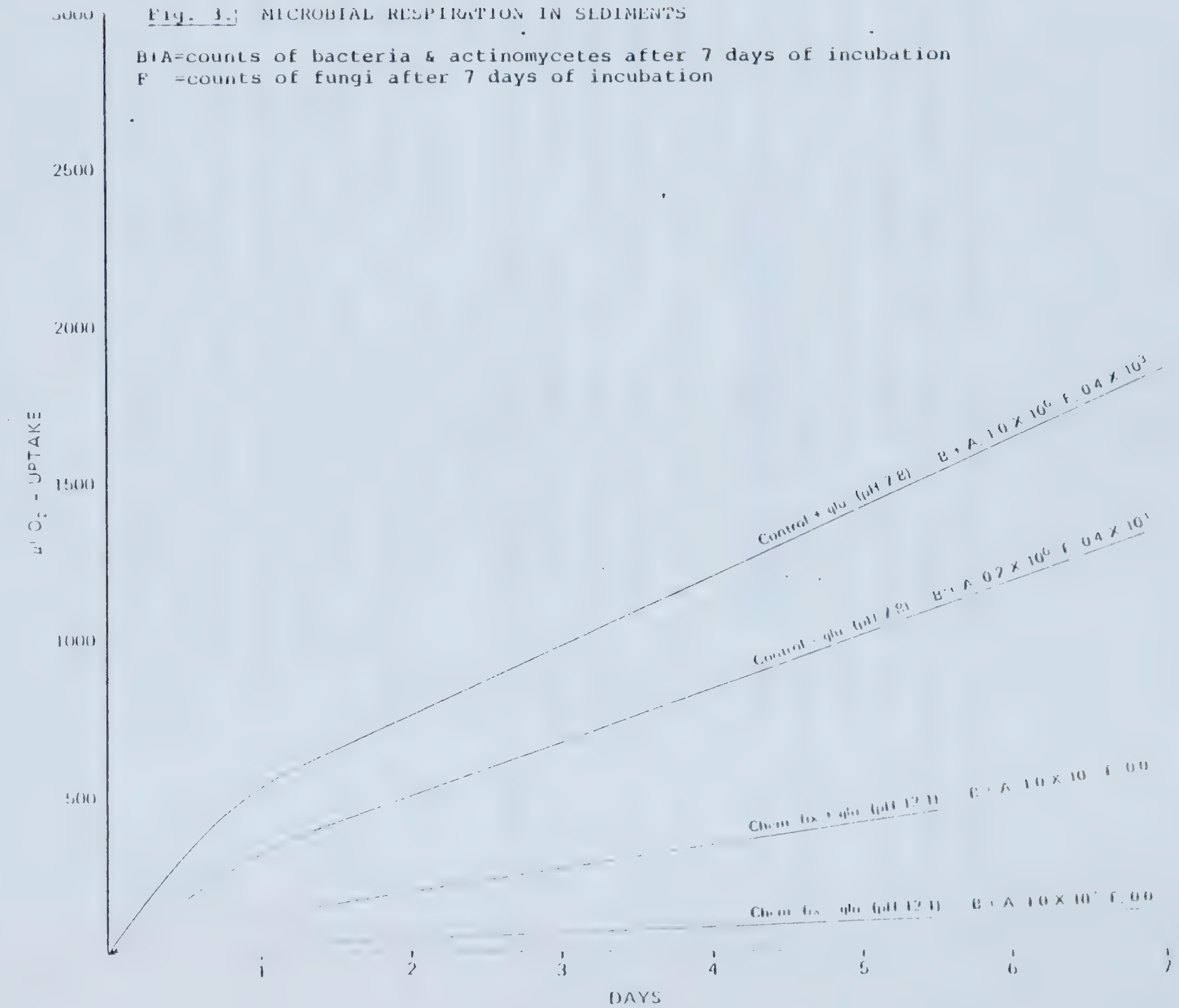

Fig. 3.1 MICROBIAL RESPIRATION IN SEDIMENTS

B+A=counts of bacteria & actinomycetes after 7 days of incubation
F =counts of fungi after 7 days of incubation

MYCORRHIZAL ASSOCIATIONS IN AMENDED OIL SANDS TAILINGS

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ABSTRACT

The mycorrhizal development of bearberry and jack pine was monitored in oil sands amended with either fertilizer, sewage sludge or a feathermoss peat or left unamended. Both plant species were mycorrhizal at the time of planting. Bearberry roots in the spoil became heavily mycorrhizal during the first growing season except in the sewage treated sand. The inhibition of mycorrhizal formation by the sewage persisted for at least two years.

During the first year, infection of jack pine roots was very low in all amendments except the peat. Infection increased in all amendments during the second year with the highest levels being found in the peat and sewage treatments. Total infection continued to increase up to the fourth year as seedlings lacking inoculum in the planting plug became mycorrhizal.

Thelephora terrestris, which was introduced in the planting plugs, was the major symbiont of jack pine in all treatments except the peat where E-strain fungi (sensu Mikola) dominated. By the fourth year, it appeared that E-strain fungi were replacing *Thelephora* in the other amendments. Other symbionts, which included *Cenococcum geophilum*, *Suillus* sp., *Inocybe* sp., *Amphinema byssoides* and *Sphaerosporella brunnea* were uncommon. It appears that once a symbiont becomes established, subsequent changes in mycorrhizal fungi are slow to occur.

Mycorrhizal associations in amended oil sands tailings

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The mycorrhizal development of bearberry (*Arctostaphylos uva-ursi* (L.) Spreng.) and jack pine (*Pinus banksiana* Lamb.) was monitored in oil sands amended with either fertilizer, sewage sludge or a feathermoss peat or left unamended. Both plant species were mycorrhizal at the time of planting. The roots of bearberry growing out into the spoil became heavily mycorrhizal during the first growing season except in the sewage treated sand (Table 1). The inhibition of mycorrhizal formation by the sewage persisted for at least two years.

During the first year, infection of jack pine roots was very low in all amendments except the peat (Table 2). Infection increased in all amendments during the second year with the highest levels being found in the peat and sewage treatments. Total infection continued to increase up to the fourth year as seedlings lacking inoculum in the planting plug became mycorrhizal.

The symbionts of bearberry are unknown but the fungi infecting jack pine could be identified. *Thelephora terrestris*, which was introduced in the planting plugs, was the major symbiont in all treatments except the peat where E-strain fungi (sensu Mikola) dominated (Table 3). By the fourth year, it appeared that E-strain fungi were replacing *Thelephora* in the other amendments (Table 4). Other symbionts, which included *Cenococcum geophilum*, *Suillus* sp., *Inocybe* sp., *Amphinema byssoides* and *Sphaerosporella brunnea* were uncommon. It appears that once a symbiont becomes established, subsequent changes in mycorrhizal fungi are slow to occur.

Table 1. Mycorrhizal infection of bearberry grown in amended oil sands.

Age-years	Control	Fertilizer	Sewage	Peat
		Percent Infection		
1	52[a]	68[a]	.01[b]	81[a]
2	74[a]	79[a]	24[b]	70[ab]

Means superscripted in each row by same letter not significantly different (p = .05).

Table 2. Mycorrhizal infection of jack pine seedling grown in amended oil sands

Age-years	Control	Fertilizer	Sewage	Peat
		Percent Infection		
1	7	5	5	25
2	33	24	49	72
4	29	60	83	91

Table 3. Isolation of basidiomycete symbionts from jack pine mycorrhizae on benomyl-MMN agar.

Symbiont	Age (years)	Control	Fertilizer	Sewage	Peat
		Frequency (%)			
Thelephora	2	73	76	44	5
Thelephora	4	62	60	49	1
Suillus	2	3	2	0	1
Suillus	4	2	1	8	0

Table 4. Infection of jack pine by the E-strain symbiont after four years

Evaluation method	Control	Fertilizer	Sewage	Peat
	Frequency (%)			
Direct count	0.2	18	21	83
Isolation on MMN^{+}	2	18	23	23

MICROBIAL ACTIVITY AND DECOMPOSITION IN AMENDED OIL SANDS TAILINGS

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ABSTRACT

Restoration of biological activity was monitored in variously amended oil sand tailings (inorganic fertilizer, sewage sludge, feather moss peat, and no amendment). Apart from assessment of enhanced organic matter and nutrient status in the amended sand - which showed peat to be most effective in improving organic matter and nitrogen status - various soil biological parameters were measured.

A short term (2 year) study showed that all three amendments significantly introduced or stimulated bacterial and actinomycete numbers in the sand (with peat being most effective). While the number of species of fungi in the sand was not significantly influenced by treatment, lengths of fungal mycelium were greatest in the peat-amended sand.

In a longer (4 year) study it was shown that, in comparison with other amendments, peat (presumably because of the high microbial inoculum it contained) was most effective in increasing microbial respiration (CO_2 efflux) and biomass C. There were no significant correlations between plant litter input, root weight and microbial biomass C.

Plant litter input (slender wheatgrass) comprised relatively quickly decaying leaves (44-50% dry wt. remaining after 1 year) and slower decaying stems (66-81% dry wt. remaining after 1 year). Amendation did not affect the short term decomposition of stems or leaves.

Microbial activity and decomposition in amended oil sands tailings

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Table 1. Microbiological characteristics of extracted oil sand (depth: 0-5 cm) 1.5 years after treatment.

Parameter	Control	Fertilizer	Sewage	Peat
Bacteria ($\times 10^7$ g^{-1})	1.9^a	7.2^b	22.3^c	67.5^d
Actinomycetes ($\times 10^4$ g^{-1})	4.3^a	1.4^b	24.5^c	1238^d
Hyphal length (m g^{-1})	43^a	60^a	70^a	690^b
Fungal spp. no.	15^a	17^a	19^a	22^a
Fungal spp./colonized particle	1.1^a	1.2^{ab}	2.2^c	1.4^b

Values in each row followed by the same letter do not differ significantly ($p = 0.05$).

Table 2. Basal respiration ($\mu l\ CO_2 \uparrow 100g^{-1}\ hr^{-1}$) of extracted oil sand (depth: 0-5 cm) after treatment.

Time (mo)	Control	Fertilizer	Sewage	Peat
0.5	66^{ab}	36^{ab}	196^{bc}	936^{de}
14	58^{ab}	194^{bc}	255^{bc}	2596^{de}
26	53^{ab}	127^{abc}	495^{cd}	1595^{de}
38	45^{a}	119^{abc}	334^{bc}	2951^{e}

Values followed by same letter(s) do not differ significantly ($p = 0.05$).

Table 3. Microbial biomass ($mg\ C\ 100g^{-1}$) of extracted oil sand (depth: 0-5 cm) after treatment.

Time (mo)	Control	Fertilizer	Sewage	Peat
0.5	4^{abc}	2^{a}	17^{bcde}	90^{ef}
14	4^{ab}	12^{bcd}	34^{de}	241^{fg}
26	5^{abc}	15^{bcde}	97^{e}	268^{fg}
38	4^{ab}	16^{c}	78^{e}	486^{g}

Values followed by the same letter(s) do not differ significantly ($p = 0.05$).

Table 4. Effect of treatment on the decomposition of filter paper and slender wheatgrass stem and leaf litter (Values expressed as % weight remaining after 12 mo).

	Treatment			
Substrate	Control	Fertilizer	Sewage Sludge	Peat
Filter paper	84 ± 14	38 ± 20	70 ± 23	75 ± 26
Leaves	46^{a}	50^{a}	46^{a}	44^{a}
Stems	81^{a}	75^{a}	66^{a}	72^{a}

Filter paper data could not be analyzed due to high variability. S.D. for each value is included. Values in each row followed by the same letter do not vary significantly ($p = 0.05$).

HEAVY METALS IN SURFACE SOILS AND VEGETATION AS A RESULT OF NICKEL/COPPER SMELTING AT CONISTON, ONTARIO, CANADA

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ABSTRACT

The soil physical, chemical and geomorphic properties were examined in an area devastated by smelting activities at Coniston, Ontario.

Soil and vegetation were sampled along a transect originating at the Coniston smelter site extending in a southeast direction for approximately twelve kilometers. The soils were analysed for various physical and chemical properties and the vegetation was analysed for total heavy metal concentrations.

The soils of the study area have elevated levels of sulphur, nickel, copper and iron with maximum total concentrations of 2.5 %, 12280 ppm, 9698 ppm, and 23.0 % respectively. Manganese and zinc do not occur in above normal soil concentrations. The pH of the soils are depressed with values as low as 2.4.

The distribution of total nickel, copper and iron in the surface soil horizons was explained using several factors in a multiple regression analysis. Distance from the smelter and organic carbon content are important factors, however the geomorphic factor plays a major role in determining the soil heavy metal distribution at the physically disturbed sites close to the smelter. The concentration of heavy metals extracted by the chelate DTPA was found to be dependent on site variables such as organic carbon content, clay content, total metal concentration and soil pH. The regression equation including total heavy metal concentration with pH and organic carbon content predicted to a greater degree the plant available concentration of the smelter contaminants.

INTRODUCTION

The Sudbury basin is the site of one of the world's largest ore deposits of nickel and copper. The INCO Metals Company's nickel production capacity at Sudbury is about one-fourth of the total capacity of the non-communist world and about three times larger than any other single nickel production facility (Curlook, 1980). As well as nickel and copper, eleven other metals are produced by INCO including iron, cobalt, silver, gold, selenium, osmium, ruthenium, rhodium, iridium, palladium and platinum. The ores of the Sudbury basin contain about eight times by weight more sulphur than nickel so that during smelting large amounts of sulphur may be released into the atmosphere. These emissions have caused drastic effects on the local Sudbury landscape. At Coniston, just east of Sudbury emissions of sulphur dioxide and heavy metal particulates initially from open air roasting beds and then from the smelter left large areas devoid of vegetation.

Most of the previous work on the soils of the Sudbury area has attempted to assess the degree of contamination and to explain the distribution of the smelter pollutants in the soil in terms of distance from the smelter and depth in the soil profile. (McGovern and Balsillae, 1972; Costescu, (1974); Hutchinson and Whitby, (1974); Cox, 1975; McIlveen and Balsillae, 1978); Freedman and Hutchinson, 1980.) Rutherford and Bray (1979) showed that elevation and expos-

ure were also important in determining the metal content in the soils near Coniston.

Many of these studies have been restricted to sites which have similar geomorphology and support the same vegetation. For example, Freedman and Hutchinson (1980) studied the accumulation of heavy metals in soils which they identified as inceptisols, along a mainly forested transect originating at the Copper Cliff smelter presently operating to the west of Sudbury. Soils to the south-east of the smelter at Coniston have been denuded of vegetation and strongly eroded (Pearce, 1976; Rutherford and Bray, 1979) so that the soil landscape has been greatly modified by erosion and present surface levels of heavy metals may bear little relationship to distance from the smelter. The heavy metal concentrations in these soils are greatly influenced by the local geomorphic conditions such that in some cases sub-surface concentrations are greater than those at the soil surface. The object of this work is to show the variations in present soil surface concentrations of heavy metals and to suggest the causal effects of some environmental factors in this manifestation.

THE PHYSICAL SETTING

The area is underlain by rocks from the late to middle Precambrian and is part of the Canadian Shield. The Wanapitei Fault runs through the area separating the highly metamorphosed biotitic, muscovitic, quartzitic and gabbro derived gneisses of the Grenville Province to the south-east

from the greatly deformed sandstones, siltstones and argillites of the Southern Province to the north-west (Grant et al, 1962; Lumbers, 1975). A thin layer of mainly sandy till moraine was deposited over the bedrock during the Wisconsin glacial advance (Boissonneau, 1966,1968) but erosion has stripped this away in many areas, exposing the bedrock (Lumbers,1975). Some of the sand and silt was deposited in lake bottoms which later became glaciolacustrine plains. Fluvioglacial valley train deposits and organic deposits are also found in the area. The climate may be classified in the Koppen system as Dfb with cold winters and warm summers. The mean annual temperature is 4.4°C with the mean daily maximum for January and July being -6°C and 25°C respectively. The mean annual precipitation is 840 mm. The vegetation prior to mining consisted of mixed borealdeciduous forest typical of this part of the Canadian Shield (Coleman, 1913). In the badly devastated area, close to the smelter isolated grass patches and scattered trees occur in a barren landscape. Trees and grass begin to occur in large numbers about 1.5 km from the smelter in the valley of the Wanapitei River. At the distant end of the transect approximately 11 km from the smelter virtually normal vegetation exists. The natural soils of the Canadian Shield are mainly of the Podzolic Order with Gleysols formed in lowland areas. Presently eroded Podzols and Gleysols dominate the landscape with Organic soils and newly formed Regosols in lowland terrain (Canada Soil Survey Committee, 1978).

MATERIALS AND METHODS

Field Methods

Soils were sampled along a transect running in a south-east direction up to a distance of approximately twelve kilometers from the Coniston smelter site (Figure 1). In this way soil environments modified by varying degrees of smelter emissions could be sampled. Soils could therefore be sampled from severely eroded sites devoid of vegetation near the smelter, to virtually physically undisturbed sites with normal forest vegetation at a distance. Two soils representative of the Canadian Shield lacking the direct influence of Sudbury smelting were sampled 55 and 135 kilometers to the south-east.

Laboratory Methods

Soil pH was measured in a 1:2 soil to liquid suspension using 0.01 M $CaCl_2$ according to Peech (1965). Particle size analysis was determined using a modified version of the pipette method of Kilmer and Alexander (1949). Total carbon and total sulphur were measured by dry combustion using the LECO induction furnace. Total element concentrations were determined after a nitric-perchloric acid digestion with nickel, copper, iron, manganese, zinc, calcium, magnesium, potassium and sodium being analysed by standard atomic absorption procedures (Canada Soil Survey Committee, 1978). Available phosphorus was extracted using a Bray and Kurtz extract consisting of 0.03 M NH_4F in 0.025 M HCl

(Jackson,1958). The molybdophosphate blue colour measured colormetrically to determine the phosphate level was produced using 1,2,4 aminonaphtholsulfonic acid as reductant. Dithionite, oxalate and pyrophosphate extractable iron and aluminum were determined using atomic absorption (Canada Soil Survey Committee, 1978). DTPA-extractable nickel, copper, iron, manganese and zinc were determined by atomic absorption after extraction with 0.2 % DTPA solution (Lindsay and Norvell, 1978).

VEGETATION

A vegetation survey of plants and trees within five meters of each site was carried out and where available Agrostis scabra (Rough Hair Grass) and Betula papyrifera (White Birch) leaves were sampled. After washing and drying these were totally digested in a Teflon bomb with H_2O_2 and HNO_3. The digest solution was diluted and analysed for nickel, copper, iron, manganese and zinc using atomic absorption.

RESULTS

A review of the major field macromorphological properties and the environmental conditions obtaining at the sample sites is rendered in Table 1. The results for the chemical analyses are shown in Tables 2 and 3. While the results show some broad patterns there are also considerable irregularities in the data from the smelter to virtually

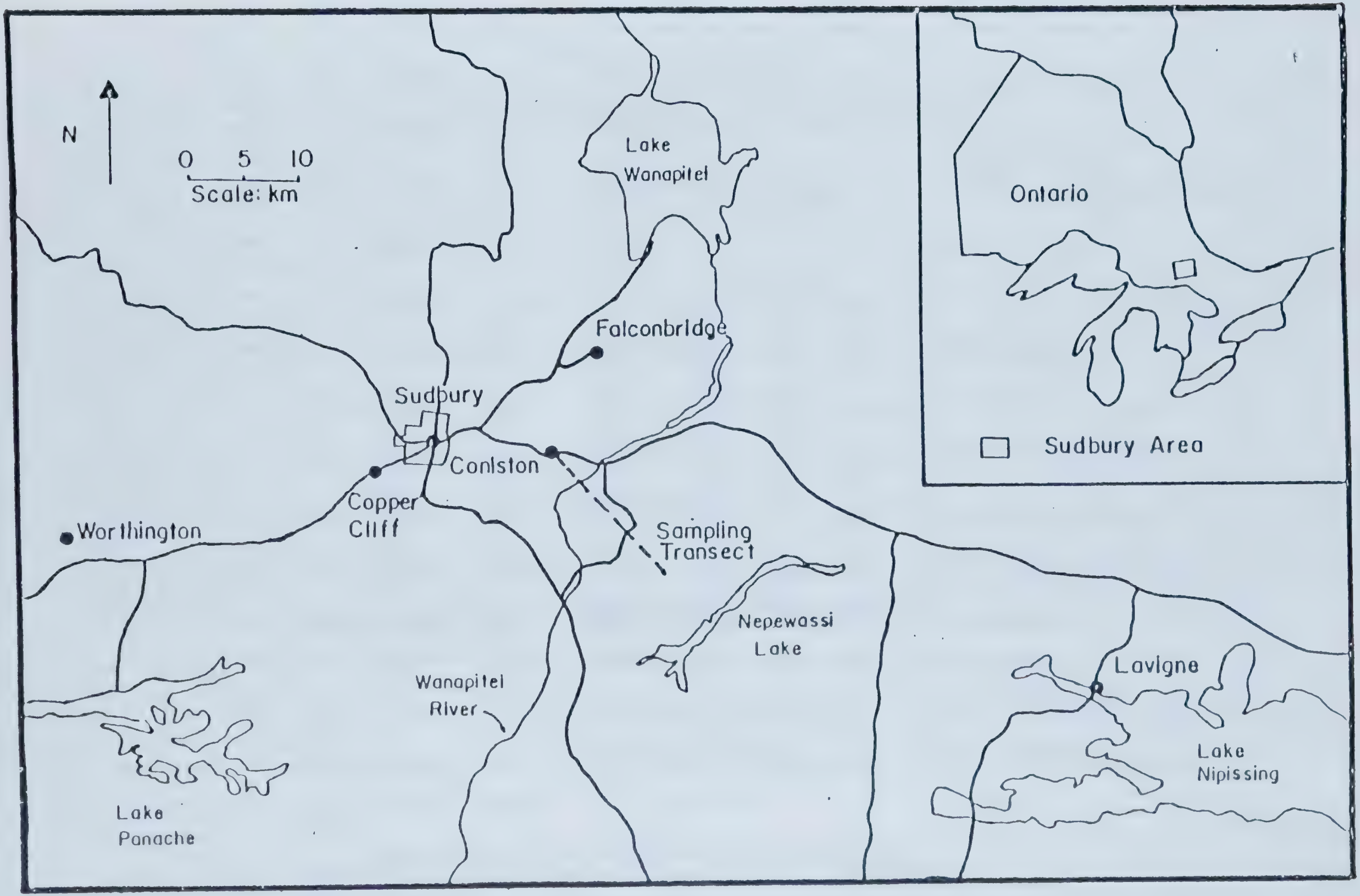

Figure 1. Location map of Sudbury
and the study area

Table 1

Morphological and environmental descriptions of surface soils influenced by nickel smelting at Coniston, Ontario.

Profile	Horizon	Depth (cm)	Colour	Texture	Situation	Other
3	A	0-10	10YR4/4	salo	400 m from the smelter near summit of a low hill.	alternating depositional layers visable.
4	Ah	0-12	5YR3/2	salo	downslope from profile 3.	old tree stumps and limbs on surface; rocky.
5	Ah1	0-13	10YR5/4	sacllo	depression 200 m from smelter	no vegetation.
8	Ah	0-20	10YR5/6	cllo	500 m from smelter; slope at edge of swamp; depositional.	no vegetation.
11	Ah	0-15	10YR5/4	sacllo	elevated swamp; depositional material over peat.	old tree stumps and limbs on surface.
16	Ah1	0-10	10YR4/4	lo	085 m from smelter; on slope of hill; depositional.	no vegetation; rocky.
18	A	0-50	10YR6/4	cllo	1 km from smelter; in erosion gulley; depositional.	wet soil conditions; sparse grass vegetation.
22	C	0-100	10YR5/4	sicl	1.2 km from smelter; in middle of roasting bed valley.	compacted soil surface; no vegetation.
24	Ah	0-10	10YR4/2	cl	1.4 km from smelter; on edge of roast beds.	forest vegetation regenerating.
25	Ah	0-15	10YR4/3	sicllo	1.5 km from smelter; in roast bed valley; depositional	old tree stumps and limbs on surface.
35	Ah	0-9	10YR4/2	salo	2.1 km from smelter; intact Podzol with depositional horizon.	sparse vegetation.
45	Ah	0-15	10YR3/1	cllo	4.5 km from smelter; poorly drained swamp site.	clumps of trees and abundant grasses.
46	Ah	0-2	10YR4/2	lo	5.5 km from smelter; well drained site.	natural vegetation.
51	Ah1	0-15	10YR4/2	sicl	11.5 km from smelter; poorly drained lowland site.	natural vegetation.
52	Ah	0-10	10YR4/2	lo	55 km from smelter; Gleysol.	natural vegetation.
53	Ah	0-15	10YR4/2	salo	135 km from smelter; Podzol.	natural vegetation.

Table 2

Particle size, pH, % organic carbon and total element analysis for soils influenced by nickel smelting at Coniston, Ontario.

Profile	Particle Size % sa	si	cl	pH	Organic Carbon %	Total Sulphur %	Total Metals (ppm) Fe (ppt) Ni	Cu	Fe	Mn	Zn	Total Major Cations (ppt) Mg	Ca	K	Na
3	74	23	4	2.4	3.9	1.8	3024	9698	199	149	129	2.0	4.1	NA	NA
4	68	27	5	3.0	2.3	1.7	3567	2625	168	167	79	2.1	2.4	2.3	0.6
5	59	27	14	2.9	1.2	0.8	1990	6294	99	302	42	4.0	3.5	NA	NA
8	42	55	3	3.5	1.3	0.2	134	530	16	221	32	3.9	3.4	2.0	0.3
11	53	41	6	2.8	2.6	1.0	1725	1301	77	140	42	1.7	2.2	1.6	0.5
16	66	30	4	3.5	1.3	0.3	952	510	40	141	37	2.5	3.6	1.2	0.1
18	18	43	40	4.0	0.3	0.0	291	181	28	445	46	7.5	6.0	9.1	0.5
22	NA	NA	NA	5.7	NA	NA	396	474	23	349	59	6.6	9.0	3.7	0.5
24	41	44	16	3.3	7.8	0.8	12280	1059	73	329	48	4.5	4.0	NA	NA
25	10	77	12	3.7	2.9	0.1	241	503	14	145	30	2.4	3.6	1.9	0.3
35	68	25	6	3.4	3.0	0.2	752	619	31	256	37	0.6	9.4	1.6	0.8
45	28	51	21	3.4	9.1	0.1	378	565	19	153	33	2.8	3.9	2.2	0.2
46	50	38	13	3.0	6.7	0.1	794	806	20	95	42	1.7	6.2	NA	NA
51	21	52	27	3.8	14.3	0.1	564	549	25	508	56	4.2	1.9	3.1	ND
52	NA	NA	NA	4.8	3.3	0.0	ND	76	17	228	45	5.7	5.5	1.7	NA
53	NA	NA	NA	4.5	1.2	0.0	ND	ND	8	325	11	0.4	1.1	NA	NA
Normal Canadian Shield Soil (McKeague and Wolynetz, 1980)							12	11		430	54				
Temperate Region Mineral Surface Soil (Brady, 1974)												1.2-15	0.7-36	1.7-33	

NA - Sample not analysed
ND - Not detectable

Table 3

Extractable elements in surface soils influenced by nickel
nickel smelting at Coniston, Ontario.

Profile	pH	Extractable Phosphorus (ppm)	DTPA Extractable Metals (ppm)					Extractable Iron and Aluminum (%)					
			Ni	Cu	Fe	Mn	Zn	Fed	Ald	Feo	Alo	Fep	Alp
3	2.4	12	2.3	6.8	113.5	0.1	0.2	8.1	0.2	19.3	ND	0.2	ND
4	3.0	33	5.2	82.1	178.4	0.2	0.2	NA	NA	NA	NA	NA	NA
5	2.9	34	17.8	79.9	109.9	1.8	0.8	2.9	0.2	5.7	0.1	0.2	0.1
8	3.5	40	7.1	54.6	21.5	0.1	0.3	0.9	0.8	0.6	1.4	0.1	0.5
11	2.8	43	133.2	117.1	132.3	0.5	0.7	5.7	0.1	6.9	0.1	0.2	ND
16	3.5	6	2.1	44.7	249.8	0.2	0.3	2.8	0.4	3.6	0.3	0.3	0.1
18	4.0	13	88.4	27.1	61.8	13.4	0.5	1.0	ND	0.4	0.2	0.2	0.3
24	3.3	37	7.5	39.3	330.8	0.7	0.3	3.9	ND	4.1	0.2	0.4	ND
25	3.7	172	86.6	132.1	293.6	0.9	0.8	NA	NA	NA	NA	NA	NA
35	3.4	33	8.6	79.5	370.1	0.4	0.4	2.3	0.2	2.1	0.2	0.3	0.1
45	3.0	28	26.9	23.8	244.1	1.3	2.2	1.7	0.5	1.5	0.5	0.8	0.5
46	3.0	38	94.4	55.7	203.6	1.2	0.6	1.2	0.2	0.9	0.1	0.4	0.1
51	3.8	46	50.8	40.1	421.1	8.5	6.4	1.6	1.0	1.1	0.9	0.5	0.9
52	4.8	35	1.4	1.5	317.2	4.8	1.9	0.6	0.3	0.5	0.2	0.2	0.2
53	4.5	48	ND	0.5	72.7	11.3	1.5	0.6	0.1	0.4	0.1	0.2	0.1

NA - Sample not analysed
ND - Not detectable

uninfluenced terrain.

The major nutrient cations calcium, magnesium and potassium generally fall within the range of normal soils in a temperate region reported by Brady (1974) and do not show any systematic trend along the transect. The minor elements nickel, copper and in some cases iron have elevated concentrations while manganese and zinc appear to be near the mean value of other Canadian Shield soils (McKeague and Wolynetz, 1980). Furthermore, as is expected the nickel, copper and iron levels decrease with distance from the smelter as has been reported in many other studies. Using Minitab Statistical Program, plots of total metal concentrations versus log of distance from the smelter were made   The relationships shown are all significant, but the degree of linearity as measured by the coefficient of determination is less than those found in some other studies (Hutchinson and Whitby (1974) and Freedman and Hutchinson (1980). This difference is due mainly to the variation in sampling methodology. In the past researchers have generally sampled forested, intact soil sites where physical disturbance by erosion has been absent or limited.

The soil landscape close to the smelter has been greatly modified by erosional forces so that the original fallout pattern of the heavy metals from the smelter has been considerably changed. Although the Coniston smelter is being considered as the only contaminant source in this study, present and past smelting at Copper Cliff and Falconbridge have likely made some contribution. The coefficients of determination for the relationships of heavy metal contents

and the log transformation of distance from the smelter and this factor accompanied by the organic carbon factor are presented in Table 4. The lack of the influence of smelter emissions on the manganese and zinc levels in the soils of the study area excludes these heavy metals from classification as soil contaminants. Chemical analyses of the ore and tailings confirm that both manganese and zinc occur in relatively low amounts and indeed INCO does not extract these metals for sale.

The relationships of total nickel, copper and iron concentrations to the organic carbon contents of the surface soil horizons, contrary to expectations show a sharp decrease at sites within approximately two kilometers of the smelter. At these sites the fallout of heavy metal particulates was so great that the influence of organic matter is insignificant. Beyond this distance an increase in organic carbon content results in a slight increase in the soil heavy metal concentrations. The coefficient of determination values indicate that nickel is more closely associated to organic matter in the soils of the study area.

Despite the improvement in the prediction ability of the model incorporating both the distance and the organic matter factors, the equations derived only explain 54, 37 and 63 % of the variation in the total nickel, copper and iron concentrations respectively along the sampling transect.

The processes of erosion and deposition have produced a wide variety of soil types within the study area. After the natural vegetation had been removed by various processes, erosional processes were and are still constantly trans-

Table 4

Equations and coefficients of determination for relationships of total heavy metal concentration with log transformation of distance from smelter and % organic carbon.

	vs log of distance	R^2	vs log of distance (x_1) and % organic carbon (x_2)	R^2
otal nickel	$y = 1764.5 - 1712.8 \log x$	.341	$y = 1144.4 - 1197.9 \log x_1 + 150.9\ x_2$	.544
otal copper	$y = 2200.4 - 2301.6 \log x$	.294	$y = 1769.8 - 3141.7 \log x_1 + 104.8\ x_2$	.365
otal iron	$y = 75.0 - 90.3 \log x$	.557	$y = 59.2 - 121.0 \log x_1 + 3.8\ x_2$	.634
otal manganese	$y = 208.6 + 59.8 \log x$	.044		
otal zinc	$y = 57.6 - 13.7 \log x$	.046		

porting large amounts of soil material to new positions in the landscape. Once strongly contaminated surface soils may be removed by erosion so that the soil presently at the surface may now be low in contaminants. On the contrary, depositional sites at a distance from the smelter may have received much more strongly contaminated soil from areas close to the smelter. The diversity of the soil landscape in the area close to the smelter makes it necessary to examine the effects of soil erosion and the heavy metal distribution at selected localities along the sampling transect.

At locality 1 the upper horizons of profiles 3, 4 and 5 consist of soil material deposited by water and the depths of these horizons increase downslope. The high heavy metal concentrations at these sites is likely due to the exposure of this material to smelter emissions at upslope sites prior to relocation by erosional forces. At locality 2, 500 meters from the smelter, profile 8 is at the edge of an elevated swamp and profile 11 is in mid-swamp. Deposited soil materials constitute the present surface soils at each site. The surface soil at profile 8 was likely transported from a subsurface horizon upslope and therefore the concentrations of nickel, copper and iron are relatively lower than at nearby profile 11. At locality 3 the upslope member, profile 16, has a 10 cm depositional horizon which has much higher metal concentrations than the lowest member profile 18, which consists of deposited subsurface horizons from upslope. Locality 4 consisting of profiles 22, 24 and 25 is located in the roasting bed valley about 1.2 kilomet-

ers from the smelter. Profile 22 has been severely eroded resulting in the exposure of a raindrop compacted C horizon relatively low in heavy metals at the soil surface. Profile 25 has been protected from severe erosion by past tree vegetation and it has a depositional surface horizon. At profile 24 forest regeneration has occurred. The surface horizon has extremely high concentrations of nickel, copper and iron, likely due to the proximity to the roasting beds and to the exposure of this new growth to continued smelter emissions.

Outside of the area where vegetation devastation has occurred and soil erosion has been severe the effects of the physical disturbance on the distribution of heavy metal contaminants is less. The data for profiles 35, 45, 46 and 51 indicate that despite the lessening of the geomorphic factor anomolies in the heavy metal concentrations occur that can not be explained by the distance from the smelter or the organic matter factors. Differences in site and soil properties can influence the total heavy metal concentrations in these profiles, which are only separated by a few kilometers. Sites 52 and 53 indicate that at much greater distances from the smelter the heavy metal concentrations decrease significantly in the surface soil horizons.

It is difficult to determine the exact source of transported soil materials. Depositional horizons are likely composed of material from several upslope locations, and therefore the heavy metal concentrations are extremely variable. Also it must be remembered that rather than the contaminants being deposited and then relocated by erosion,

movement of soil materials was occurring as smelter emissions were taking place. Despite the complexity and qualitative nature of this analysis, the geomorphic factor in combination with the distance from the smelter and organic matter factors provides a useful model for explaining the distribution of nickel, copper and iron in the soil landscape.

EFFECT OF SOIL PROPERTIES ON DTPA-EXTRACTABLE CONTAMINANTS

The concentration of heavy metal contaminants removed from soils by "plant available" extractants such as DTPA is dependent on the soil's physical and chemical properties. Total metal concentration, organic matter content, clay content and soil pH are all factors which have an effect on the concentration of nickel, copper and iron extracted from the soil by DTPA. A multiple regression analysis of these relationships yielded the coefficients of determination listed in Table 5 and showed the following:

i The amount of nickel extracted is more influenced by the organic carbon and clay contents of the soil than by the total nickel concentration or soil pH.

ii DTPA-extractable copper is more strongly associated with the total concentration of copper. Significant relationships exist with organic carbon and pH however clay plays a minor role.

Table 5

Coefficients of determination for relationship of DTPA-extractable heavy metals with total metal concentration (1), organic carbon (2), soil pH (3) and clay content (4).

	1	2	3	4	2 & 3	2 & 4	2 & 1	3 & 4	3 & 1	1 & 4	1,2,3	1,2,4	1,3,4	2,3,4	1,2,
DTPA-Ni	.011	.440	.044	.172	.457	.489	.458	.236	.100	.248	.458	.265	.265	.491	.49
DTPA-Cu	.321	.426	.077	.070	.446	.440	.499	.161	.323	.355	.449	.501	.361	.448	.50
DTPA-Fe	.046	.195	.181	.010	.274	.184	.321	.195	.321	:136	.428	.323	.347	.274	.42

iii Soil clay content and total iron concentration do not have a great influence on DTPA-extractable iron however organic carbon and pH do.

The factors included in this analysis may only partially explain the amount the of these metals extractable from these soils by DTPA. Specific conditions at each site and the physical and chemical characteristics of the soil sample play a role in the amount of heavy metal extractable by this chelating agent.

PLANT HEAVY METALS

The grass Agrostis scabra was sampled at ten sites along the soil sampling transect and analysed for the total concentration of nickel, copper, iron, manganese and zinc. The grass concentrations were considered to be the plant available concentrations and were compared with the total and DTPA-extractable metal concentrations in the surface soil horizons at each site using the linear regression approach. These results are listed in Table 6. Soil pH and organic carbon content were incorporated into a multiple regression analysis. The results suggest that for the smelter contaminants deposited in the soils of the study area a total extraction accompanied by the soil pH and the organic carbon content is most useful in predicting the amount of nickel, copper and iron available for uptake by the grass Agrostis scabra. Extremely low pH values and other soil factors in these highly contaminated soils may

Agrostis scabra and and surface soil concentrations of heavy metals for soils influenced by nickel smelting at Coniston, Ontario.

Profile	Agrostis scabra Total metals (ppm)					Total metals (ppm) Fe (ppt)					DTPA-extractable metals (ppm)				
	Ni	Cu	Fe	Mn	Zn	Ni	Cu	Fe	Mn	Zn	Ni	Cu	Fe	Mn	Zn
1	58	52	1183	143	22	6956	4232	230	222	104	26.5	43.3	60.9	0.6	0.6
21	41	11	225	143	22	1297	1106	46	248	55	20.2	107.3	216.0	3.3	0.9
34	11	11	134	490	40	400	550	28	259	42	22.5	101.1	162.0	0.8	0.5
36	11	16	130	393	17	487	461	25	322	45	15.8	53.1	360.7	4.6	0.4
37	23	15	87	314	21	1023	1536	38	455	112	9.3	85.2	313.2	1.8	0.3
38	15	4	61	80	17	1967	1124	47	71	54	40.9	46.0	557.1	0.7	0.9
41	32	7	135	113	19	482	519	12	88	22	100.0	105.7	236.5	0.3	1.7
45	37	7	165	422	27	368	565	19	153	33	26.9	23.8	244.1	1.3	2.2
46	43	9	495	280	29	794	806	20	95	42	94.4	55.7	203.6	1.2	0.6
49	43	7	72	449	41	1553	1162	22	634	130	283.5	80.4	193.1	12.5	5.8

prevent the DTPA from accurately determining plant available concentrations of these heavy metal contaminants.

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RECLAMATION OF DYKELAND FOR AGRICULTURAL PRODUCTION IN NEW BRUNSWICK

by

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RECLAMATION OF DYKELAND FOR AGRICULTURAL PRODUCTION IN NEW BRUNSWICK

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ABSTRACT

Coastal marshland along the Bay of Fundy protected by dykes from tidal flooding was successfully utilized for agricultural production from the 1600's to the 1920's. Decreasing hay prices and availability of cheap labor reduced the utilization of these dykelands resulting in the loss of dykes and lack of dykeland drainage maintenance.

From the late 1940's to the early 1970's, over 90km of dykes, 69 aboiteaux or gated tidal culverts and 4 gated dams were constructed to reclaim over 11,000ha of agricultural and over 3,000ha of non-agricultural dykelands. Agricultural utilization of these reclaimed dykelands increased slowly due to the lack of adequate main and field drainage systems suited to modern farm equipment and crop production methods.

Reclamation of these protected dykelands since 1975 has involved the development of main and field drainage systems. Over 13,000m of main outlet drainage ditches affecting over 1,000ha have been constructed. Land forming, a method of improving surface drainage of silt loam soils, has been utilized to drain over 500ha greatly improving field drainage and crop production when compared to the traditional dykeland drainage method of dale ditching.

More reclamation and development of the poorly drained areas of the dykeland in New Brunswick is required before the full agricultural potential of the land will be realized.

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Reclamation of Dykeland for Agricultural Production in New Brunswick

Clair Gartley, P. Eng.

Introduction

The coastal marshland along the Bay of Fundy consists of silt beds deposited by high tides. Dykelands are areas of these silt beds which have been protected from high tides by the construction of dykes. Once protected from the high tides, marshland which originally produced saline resistant vegetation can be used to produce common agricultural crops.

There are dykelands in both New Brunswick and Nova Scotia which have successfully produced agricultural crops for over 300 years. The Bay of Fundy dykelands in New Brunswick are located in Albert and Westmorland counties along the Petitcodiac, Memramcook, Tantramar, Aulac and Missaquash Rivers.

The first dykes to protect marshland were constructed by Acadian settlers. The English settlers who followed also found it feasible to produce good agricultural crops on dykeland and the construction of dykes continued. It was estimated by Aalund and Wicklund (1950) that there were 19,332 hectares of dykeland in the region at the head of the Bay of Fundy in the late 1940's.

Generally, the production of agricultural crops on the dykelands had increased until the early 1920's. The main crop produced was hay which was in great demand to feed the nearly 4 million horses in Canada at that time. But the gasoline engine began to replace the work of horses and the demand for hay began to decrease. By 1923 hay prices had fallen from $31. per tonne to $14. per tonne and by 1933 hay was selling at $11. per tonne as reported by Haase and Packman (1953) and Baird (1954). Also, there became a scarcity of the large amount of labor required to construct

and maintain dykes and to farm the dykelands due to expanding industrialization and World War II. By the late 1940's, many areas of dykeland were not being actively farmed and some of the dykes protecting these areas had been eroded. Since the dykelands were still recognized as a valuable agricultural resource, some repair and maintenance of dykes was done. But a co-ordinated effort of dykeland reclamation was required to reconstruct and maintain a dyke system at less cost than spot repair and maintenance of the existing system.

In 1948, the Federal Government passed the Maritime Marshland Rehabilitation Act in an effort to begin reclaiming of the dykelands in New Brunswick and Nova Scotia. The Maritime Marshland Rehabilitation Administration (M.M.R.A.) was established in Amherst, N.S. and reclamation work began. The Federal Government took the responsibility of constructing the required dykeland protective structures and the Provincial Governments assumed the responsibility of developing and returning the land protected by the dykes to active agricultural production. Both the Provinces of New Brunswick and Nova Scotia passed Marshland Reclamation Acts to facilitate dykeland reclamation and development.

Most of the required modern dykeland protective structures were constructed from 1950 to the early 1970's but utilization of the reclaimed dykeland did not follow as expected. Problems were encountered due to the fragmentation of the dykeland ownership, unsuitability of the traditional dykeland drainage systems to modern agricultural equipment and production methods, and the often unstable economics of the livestock based agricultural industry in the dykeland areas as reported by MacIntyre and Jackson (1975).

Since the early 1970's, utilization of dykeland for agricultural production has begun to increase. This has occurred

because of the reclaiming of the marshlands by the construction of an adequate dykeland protective system and because of the reclaiming of the dykeland by development of adequate main outlet and field drainage systems.

Marshland Reclamation

The Dykeland Protective System.

The dykeland protective system consists of a dyke to protect the land from tidal flooding and an aboiteau or gated sluice which drains fresh water from the protected marshlands. Gated dams are used to outlet rivers which drain through the dykeland while holding back the tidal waters. There are approximately 11,133 hectares of agricultural and 3,111 hectares of non-agricultural protected dykelands in New Brunswick as listed in Table 1.

TABLE 1. DYKELAND AREAS IN NEW BRUNSWICK
(M.M.R.A. STATISTICS, 1964)

LOCATION OF DYKELAND	AGRICULTURAL DYKELAND (HECTARES)	NON-AGRICULTURAL DYKELAND (HECTARES)
North of the Tantramar Dam & the T.C.H.	4,538	2,645
South of the Tantramar Dam & the T.C.H.	1,406	45
Eastern Albert County	2,196	362
Along the Petitcodiac & Memramcook Rivers	2,916	59
Saint John County	77	---
TOTAL	11,133	3,111

When the dykelands were reclaimed by the M.M.R.A. many small areas of dykeland or marsh bodies were consolidated into larger areas to reduce the length of dyke and number of aboiteaux required to protect the area. Improved dyke and aboiteau design and the availability of modern construction materials and equipment allowed the M.M.R.A. to construct more durable dykes which could withstand stronger tidal forces and larger aboiteaux capable of discharging runoff from greater areas of dykeland.

Dykes constructed to protect the New Brunswick dykelands have a height of 3 m to 4 m above the inside marsh level, a top width of 2.5 m and side slopes of 2:1 to 3:1. Most of the material used to build the dykes was excavated from a borrow pit located on the outside of the dyke. Dykes constructed facing a large area of open water and subjected to sea pounding were faced with rock to decrease wave and tidal erosion.

After the salt had leached from the silt material used to construct the dyke, it was limed, fertilized and seeded to a grass mixture.

Each year the grass is mowed and removed from the dyke. Livestock are not allowed to graze on the dyke and vehicle travel is limited to prevent its deterioration. Areas of a dyke which have settled or have been eroded by high tides are repaired by topping the dyke with additional material and later reseeding. Additional rock facing is placed as required.

On the inside or upland side of a dyke there is located an inner dyke road which was constructed to provide access to the dykes and aboiteaux. An inner dyke ditch runs along the inside perimeter of the road. This ditch provides drainage for the road and the dyke while aiding drainage of land bor-

dering the inside of the dyke. Without this ditch, deterioration of the dyke and inner dyke road would occur more quickly.

A typical dyke is shown in Figure 1.

Aboiteaux were strategically placed at various intervals along the dykes to provide for drainage of the protected lands and to drain runoff from uplands draining onto the dykelands. The M.M.R.A. eliminated many small aboiteaux by consolidating small marsh bodies into larger areas. Large aboiteaux were constructed to provide drainage of the larger protected areas. Gated dams were constructed on rivers draining through the dykelands to eliminate the many small aboiteaux that were located upstream at each outlet to these rivers.

The aboiteau first built by the Acadian settlers was constructed of hewn timbers attached by wooden pegs. Wooden flap gates were suspended in the aboiteau sluiceway. The flap gate was hinged so that it would be pushed shut by a rising tide, stopping the salt water from entering the protected dykeland. As the tide receded the fresh water draining from the protected land would push the aboiteau gate open and drain into the tidal channel below the aboiteau.

The aboiteaux constructed by the M.M.R.A. in New Brunswick function on the same flap gate principle as the Acadian aboiteaux. Most of these aboiteaux were built with wooden sluices (culverts) and had bronze flap gates. Some of these aboiteaux have now been partially or totally replaced using corrugated steel culverts and steel gates. Some aboiteaux have also been fitted with concrete inlet and outlet structures. A typical aboiteau structure is shown in Figure 2.

There are over 90 km of dyke and 69 aboiteaux used to protect dykeland in New Brunswick as listed in Table 2.

TABLE 2. LENGTHS OF DYKES AND NUMBER OF ABOITEAUX FOR NEW BRUNSWICK MARSH BODIES.

MARSH BODY		LENGTH OF DYKE (M)	NO OF ABOITEAUX
NB-56	North of Tantramar Dam & T.C.H.	3,626	3
South of Tantramar Dam & T.C.H.:			
NB-24	Aulac	12,867	5
NB-16	Dixon Island	5,399	4
NB-37	Sackville	1,801	2
NB-5	Westcock	6,480	7
Eastern Albert County:			
NB-30	Calkins	1,892	1
NB-51	Hopewell Hill	4,423	4
NB-17	New Horton	1,795	1
Along Petitcodiac River:			
Above Dam:		---	-
Below Dam:			
NB-19	Beaumont	3,081	3
NB-11	Belliveau Village	529	1
NB-45	Chartersville	2,529	2
NB-25	Dock	---	-
NB-26	Dover	1,426	1
NB-18	Fox Creek	316	1
NB-20	Gautreau Village	3,412	3
NB-47	Hillsborough	6,119	5
NB-14	Lower Coverdale	2,816	3
NB-12	Pre d'en Haut	1,802	2
Along Memramcook River:			
Above Dam:		829	-
Below Dam:			
NB-27	College Bridge	6,500	4
NB-13	Dorchester	6,998	5
NB-21	Memramcook West	10,695	7
NB-6	Taylor Village	5,259	5
	TOTAL	90,594	69

Gated dams used to protect dykelands were built in the 1960's and early 1970's on the Petitcodiac, Shepody, Memramcook and Tantramar Rivers as listed in Table 3.

TABLE 3. LOCATION AND SIZE OF DAMS PROTECTING NEW BRUNSWICK DYKELANDS.

STRUCTURE LOCATION	RIVER	GATE SIZE
Harvey Bank, Albert Co.	Shepody	2 - 4.9 m X 6.1 m
St. Joseph, Westmorland Co.	Memramcook	2 - 4.9 m X 4.6 m
Moncton, Westmorland Co.	Petitcodiac	5 - 6.1 m X 9.1 m
Sackville, Westmorland Co.	Tantramar	2 - 4.9 m X 4.6 m

Each dam is fitted with cable operated gates suspended in concrete sluiceways. When fresh water must be drained from the rivers, the gates are raised at low tide. The gates are manually controlled because of daily water level and tide cycle variations and because they require frequent inspection to insure their proper operation. The Tantramar River dam structure is shown in Figure 3.

The Province of New Brunswick and Nova Scotia assumed the responsibility for maintenance of their respective dykeland protective structures since completion of their construction by the Federal Government.

DYKELAND RECLAMATION

The Dykeland Soil

The Southeastern New Brunswick Soil Survey Report designated the dykeland soil as Acadian. The soil may be an A_1, A_2, A_3, A_4, or A_5 with the A_1 being very well drained and the A_5 being swampy or very ill drained Acadian soil. The soil is composed of approximately 12% sand, 52% silt and 36% clay in the top 0.3 m layer and has a textural classification of silty clay loam. This composition varies depending on the natural and/or artificially controlled tidal deposition which may have occurred at an area of dykeland. The soil normally has a very high magnesium and potash (K_2O) content, a low to medium calcium content and a very low phosporus (P_2 O_5)content. Soil ph will vary from 5.0 to 7.0.

Dykeland soils in New Brunswick normally have a very low hydraulic conductivity. Although good material for dyke construction, the dykeland soils are difficult to drain because of their low hydraulic conductivity and flat topography. Once properly drained these soils are very productive and will produce good yields of grasses, legumes, feed grains and vegetables.

The 'Daled' Drainage System

Dykelands which are drained using the daled drainage system have shallow ditches 0.3 m to 0.6 m in depth spaced approximately 20 m apart. These ditches are dale ditches and the width of land located between two dale ditches is a dale. The length of a dale may vary from 100 m to 500 m depending on the field topography. Cross drains or very small ditches are used to drain low areas of the dale into the dale ditch. To fit irregular shapes of dykeland along the edges of uplands, creeks and rivers the dales may be curved or triangular in shape. Dale ditches are drained by a larger ditch or vent ditch which drains into a main ditch or creek. The main ditch or creek drains into a river or to an aboiteau.

The daled system of drainage has been used on dykelands in New Brunswick since the 1600's and was adequate when horses were used for pulling farm implements. Short, narrow, non-rectangular dales are not conducive to the operation of most modern farm equipment; maintenance of dale and vent ditches is expensive, and the daled system does not provide adequate drainage for production of good yields of high quality crops required by a modern, efficient farm operation.

Because of the difficulties in draining dykeland using the daled system and because many drainage outlets from the dykeland were not adequate, development of improved drainage systems began in the early 1970's resulting in the design and construction of new main, secondary and field drainage systems.

The Main Drainage System

Each area of dykeland requires a main drainage system to properly outlet fresh water runoff from the dykeland to an aboiteau or to a river draining to a gated dam. The main drain system may consist of a network of creeks and/or large ditches which extend through the dykeland. The main drainage system is planned, designed and constructed according to the drainage requirements of the area of dykeland that it affects.

Main drainage system construction involves the excavation of main ditches to the design grades, placement and backfilling of the required culverts, and the levelling of ditch excavation spoil. Main drainage ditches vary from 1.5 m to 4.5 m in depth, and have side slopes of 1.5 - 2.5:1. Ditch bottom widths vary from 1.0 m to 2.0 m.

Approximately 14,000 m of main drainage system construction affecting over 1,000 ha of dykeland in New Brunswick has been completed since 1978 as listed in Table 4.

TABLE 4. LOCATION AND DESCRIPTION OF DYKELAND MAIN DRAINAGE PROJECTS FROM 1978 to 1981.

MARSH LOCATION	PROJECT	DITCH LENTH (Metres)	AREA DRAINED (Hectares)
North of Tantramar Dam & T.C.H.	La Coupe	1,585	101
	Lower Aulac	1,006	61
	West	2,850	334
	Tolar Thompson	3,505	301*
South of Tantramar Dam & T.C.H.	Upper Aulac	1,467	41
Along Memramcook River - Below Dam	College Bridge	1,585	178
	S.W. Dorchester	1,951	42
	TOTAL	13,949	1,058

* Project not completed.

The Secondary Drainage System

Secondary or vent ditches are required to drain runoff from the dykeland field drainage system to the main drainage system. Vent ditches are normally constructed through low areas of the dykeland and may be located at either one or both ends of a field. Often vent ditches are excavated through wet areas to drain those areas before field drainage construction begins. Vent ditches vary from 1.0 m to 1.5 m in depth and have side slopes of 1.0 - 1.5 : 1. Bottom slopes vary from 0.1% to 0.3%.

The Field Drainage System - Land Forming

The technique of land forming poorly drained silt loam soils has been used in some areas of North America since 1947 as reported

by Wojta, et al. (1960) but only gained acceptance for dykeland fiel drainage in New Brunswick since 1975. Land forming is the process of mechanically moving soil to change a field's contours to provide for improved surface drainage. When compared to the daled drainage system, land forming has been shown to greatly improve drying of dykeland soils resulting in a longer cropping season, improved crop quality, increased crop yield and greater field trafficability.

Land forming construction involves the moving of dykeland soil into regular, parallel forms or crowns which run from one end of a field to the other. The crown or high area of the formed land drains into a run or the low area of the formed land. The run is graded or ditched to drain into a vent ditch at the end of crown. Figure 4 shows a typical plan view and cross-section of a formed and a daled dykeland field draining into the same main ditch.

The width of a land form may vary from 35 m to 70 m. The slope of the form from the bottom of the run to the top of the crown is usually 1.0% to 3.0%. Land forming is designed to eliminate as many dale ditches as possible while consolidating small irregular fields into larger rectangular fields.

516 ha of dykeland has been land formed in New Brunswick since 1975 as listed in Table 5.

TABLE 5. LOCATION AND SIZE OF COMPLETED DYKELAND FORMING PROJECTS 1975 to 1981.

MARSH LOCATION		AREA FORMED (HECTARES)
North of Tantramar Dam & T.C.H.		188
South of Tantramar Dam & T.C.H.		46
Eastern Albert Co.		58
Along Petitcodiac River:	Above dam	14
	Below dam	4
Along Memramcook River:	Above dam	20
	Below dam	186
	TOTAL	516

Dykeland Construction Equipment

Various pieces of construction equipment are utilized for protective structure maintenance and drainage construction on dykelands. Heavy equipment such as crawler-mounted draglines and crawler tractors are used for dyke topping, main ditch excavation and land forming. Lighter equipment such as backhoes and land levellers are used for vent ditching and field levelling.

The publication "Machines for Marshland Ditching" (1963) reports on a variety of ditch excavation equipment that has been used on dykeland. Small farm tractor mounted rotary ditch excavators are commonly used for dale ditch and land formed run ditch excavation.

The most common types of dykeland reclamation construction equipment are listed in Table 6.

TABLE 6. DYKELAND RECLAMATION CONSTRUCTION EQUIPMENT AND ITS USES.

EQUIPMENT	SIZE	USES
Dragline	3/4 - 1 CY 18 - 25 ton	Dyke topping Aboiteaux repairs Main ditch excavation
Hydraulic, Crawler Mounted Backhoe	3/4 - 1 CY	Main ditch excavation Vent ditch excavation
Industrial Backhoe Loader	60 - 85 HP	Vent ditching excavation
Rotary Ditcher Mounted on Farm Tractor	Tractor: 45 - 100 HP	Dale (lateral) ditch excavation Land formed 'run' ditch excavation
Crawler Tractor	65 - 150 HP	Dyke levelling Land forming Ditch spoil levelling Road construction
Grader	100 - 150 HP	Road maintenance
Land Levellers	3.7 m width	Field levelling & smoothing

Conclusion

Dykelands which only produced one crop of low quality baled hay are now producing up to 3 crops of high quality grass silage per year. Farmers who have reclaimed and developed their poorly drained dykeland fields are now able to produce a wider variety of crops using modern equipment and management techniques giving them more options for utilizing and more incentive for fully developing their dykelands.

Reclamation of the dykelands in New Brunswick is a continuing process. Adequate protective structures have been constructed and are maintained but further work such as main, secondary and field drainage development, research and evaluation of new dykeland drainage techniques and crop production systems is required.

If dykeland reclamation is not continued, the potential of the dykeland base for agricultural production will not be realized and many Southeastern New Brunswick farm operations will lose a large part of their crop production base.

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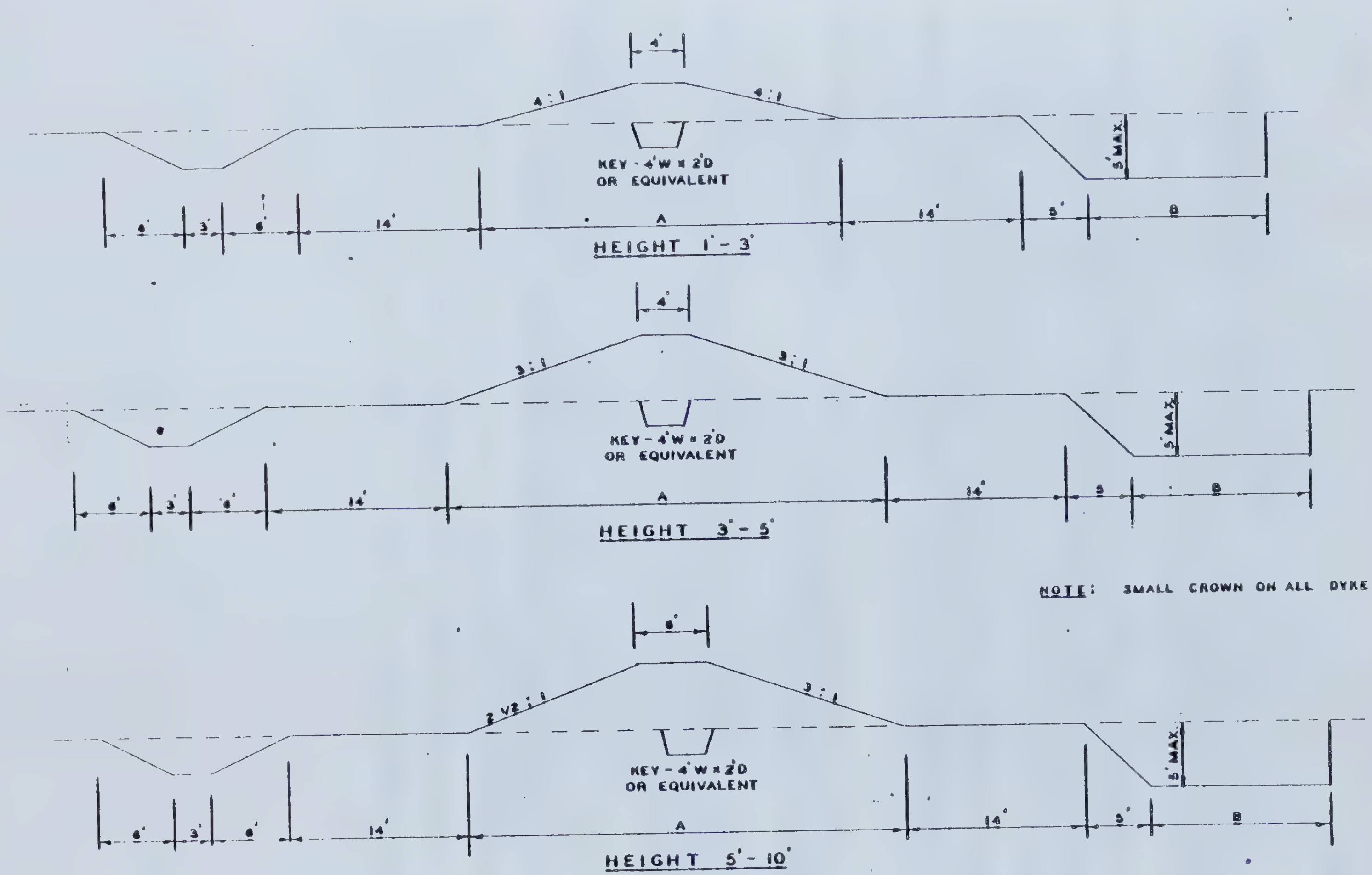
STANDARD DYKE



STANDARD DYKE — HEIGHT - 1'-3'				
QUANTITIES & DIMENSIONS				
HEIGHT	CU. YDS/FT	CU. YDS/FT +10%	A	B
1'-0"	.30	.33	12.0'	
2'-0"	.80	.88	20.0'	
3'-0"	1.78	1.96	28.0'	

STANDARD DYKE — HEIGHT - 3'-5'				
QUANTITIES & DIMENSIONS				
HEIGHT	CU. YDS/FT	CU. YDS/FT +10%	A	B
3'-0"	1.44	1.58	22.0'	5.3'
4'-0"	2.37	2.61	28.0'	10.3'
5'-0"	3.52	3.87	34.0'	16.5'

STANDARD DYKE — HEIGHT - 5'-10'				
QUANTITIES & DIMENSIONS				
HEIGHT	CU. YDS/FT	CU. YDS/FT +10%	A	B
5'-0"	3.66	4.03	33.5'	17.3'
6'-0"	5.00	5.50	39.0'	24.5'
7'-0"	6.55	7.20	44.5'	32.0'
8'-0"	8.30	9.13	50.0'	42.3'
9'-0"	10.25	11.28	55.5'	53.0'
10'-0"	12.41	13.65	61.0'	64.7'

Fig. 1. - Typical dyke

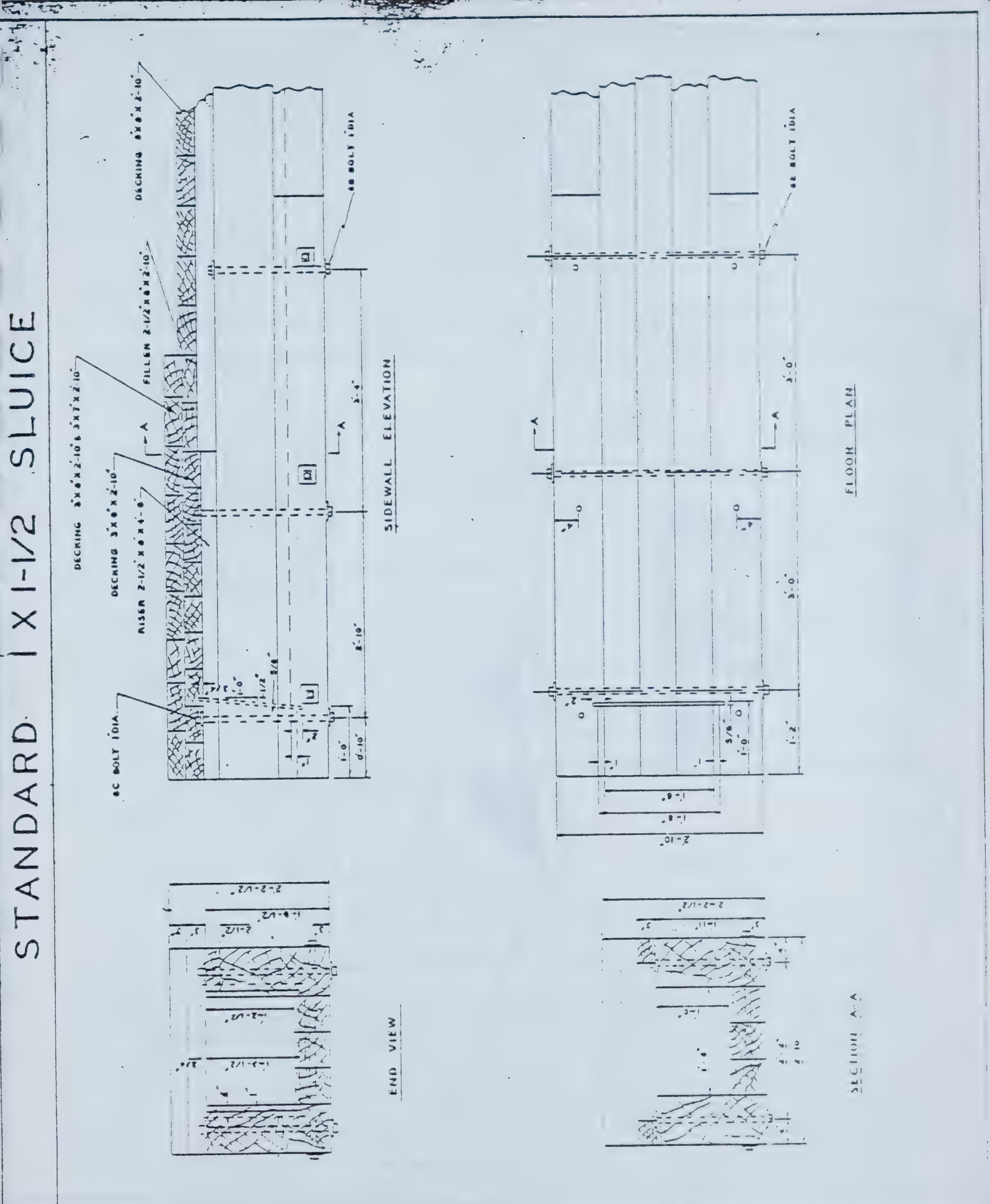


Fig. 2. - Typical wooden aboiteau sluice structure.

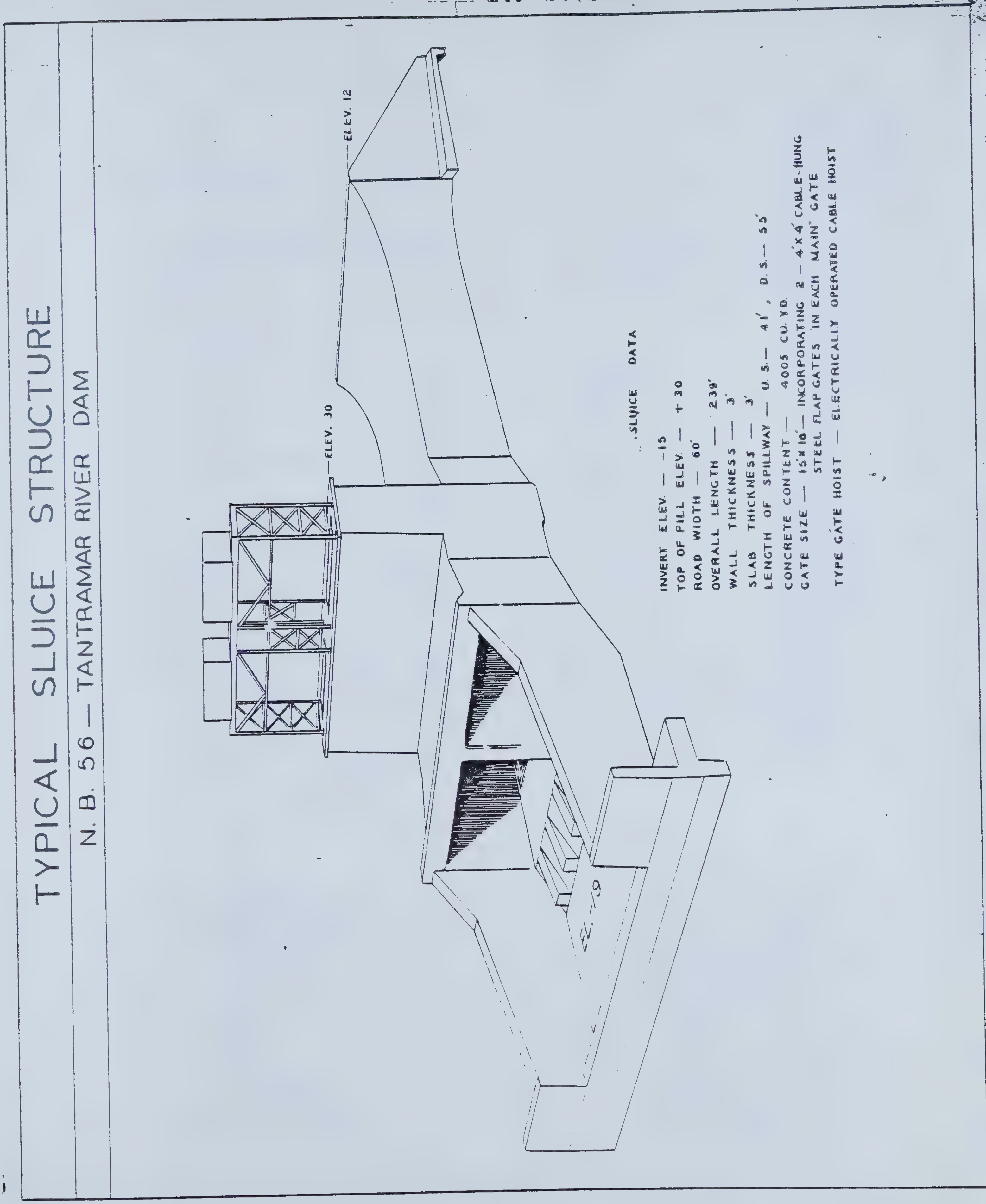


Fig. 3 - Typical gated dam structure.

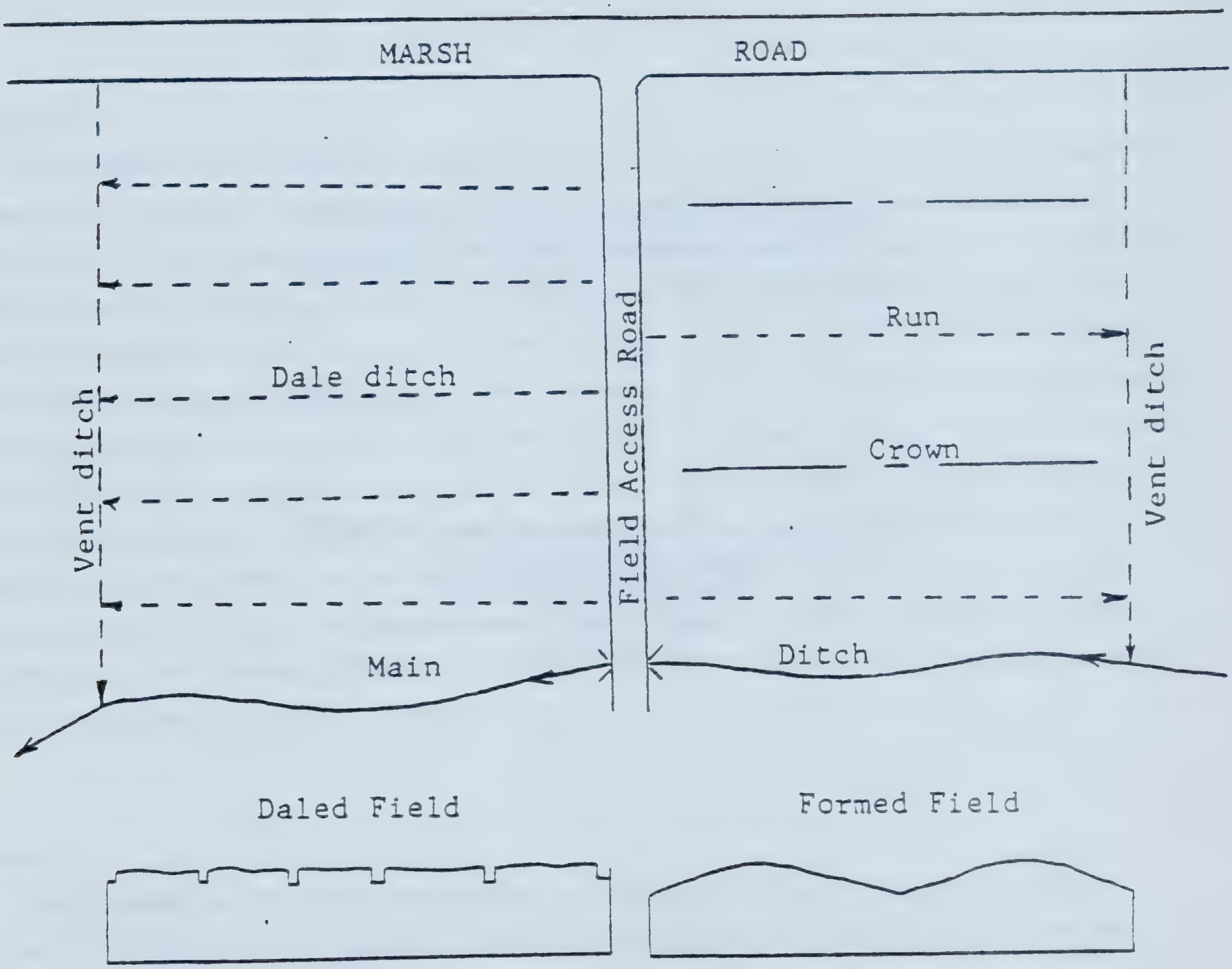


Fig. 4 Typical plan view and cross-section of a daled and a formed dykeland field.

RECLAMATION AND PUBLIC SECURITY AT MINING SITES IN THE SOUTHERN PART OF QUEBEC PROVINCE

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RECLAMATION AND PUBLIC SECURITY AT MINING SITES IN THE SOUTHERN PART OF QUEBEC PROVINCE

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Abstract:

This paper describes the present situation in the southern part of Québec concerning abandoned mines and quarries and open-pit as well as underground excavations. The first section provides recent data on the number of sites involved, their location, the rock or ore mined, the areas and the present land-use which should permit a better understanding of the problem as a whole. The dangerous sites are identified as well as the sites that have been covered with concrete slabs or fenced in. Solutions will be proposed for the unsafe excavations taking into account the specific danger they represent. Rehabilitated excavations are also identified and described. Some have been naturally or artificially reclaimed and others rehabilitated (converted to a specific secondary use). Finally, a prospective view of the evolution of the situation in the near and distant future is presented, taking into account present trends and the various legal constraints.

Résumé:

Cet exposé se propose de dresser un portrait le plus fidèle possible de la situation actuelle dans la partie méridionale du Québec en matière de mines et carrières abandonnées. Tout d'abord, des données récentes sur le nombre de sites, leur localisation, la roche ou minérai extrait, leur superficie et l'utilisation du sol actuelle sont présentées afin de bien situer le cadre dans lequel s'inscrit plus particulièrement les sites dangereux et les sites réhabilités. Les sites dangereux sont dénombrés et identifiés par rapport à ceux qui ne présentent aucun danger spécifique. De plus, certains sites ont fait l'objet de mesures de protection comme les dalles de béton ou les clôtures. En fonction des types de dangers identifiés, des solutions précises sont recommendées. Les sites réhabilités c.a.d. qui ont été restaurés naturellement ou artificiellement, et ceux qui ont été véritablement réaménagés sont localisés et décrits brièvement. Enfin, un essai de prospective évaluera l'évolu-

tion future de la situation en fonction du dynamisme actuel et du cadre légal du Québec.

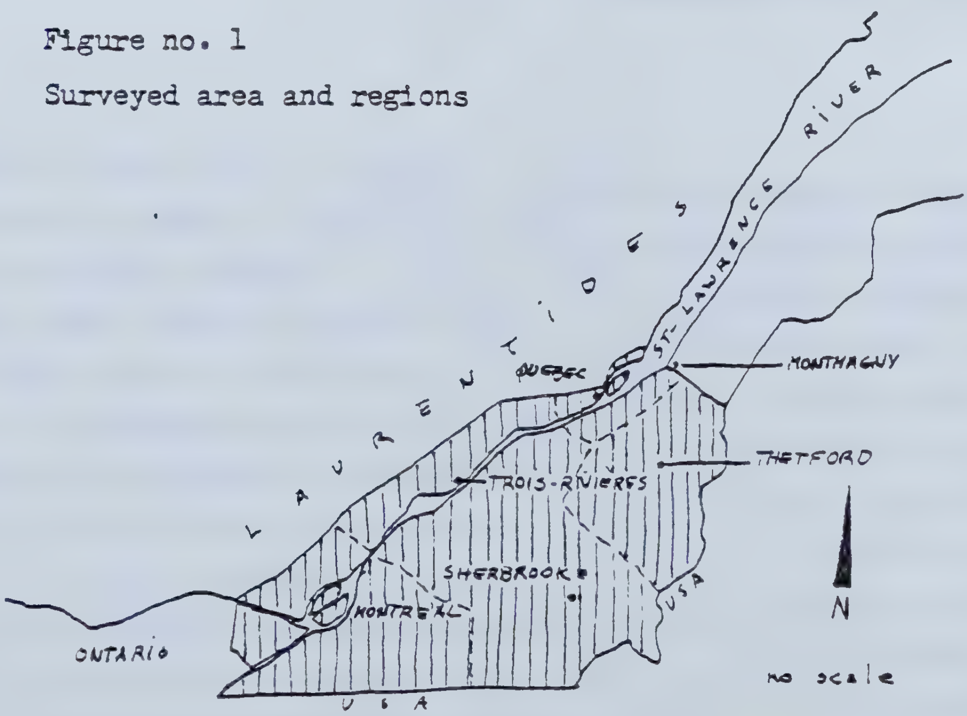
Introduction

An inventory of active and abandoned open-pit mines and quarries in Southern Québec was conducted in the summer of 1980 as part of a master's thesis on rehabilitation of derelict mining land (BOIVIN,D.J.,1981b) and some of the data collected was published as a short article in the winter issue of GEOS (BOIVIN, D.J.,1981a).Over the following summer, complementary data were gathered for the various underground workings in the region. The data for the surface and the underground sites presented today give a complete and reliable portrait of the present situation in the study area.

This survey covers all of the St-Lawrence Lowlands and the southwest portion of the Appalachian mountains; the exact limits are the american border on the South, the southern edge of the Laurentians on the North, the Ontario border on the west and the municipalities of Chateau-Richer (north shore) and Montmagny (south shore) on the East (see figure no. 1). A similar survey is now underway in the Gatineau region and eventually the entire province will be covered. Another survey is now almost completed for the Abitibi/Chibougamau region and are now piloted by the Québec ministry of Energy and Resources (Serviee du Milieu minier).

Figure no. 1

Surveyed area and regions



This paper gives special attention to public safety and to rehabilitation schemes that have been successfully completed in the area delimited above. As a result of this presentation, it is hoped that more attention will be devoted to abandoned openings, to their improved safety and control measures and their eventual rehabilitation.

Because of the short time available and the large amount of data, I will make only a few observations and will await your questions on more specific aspects that might interest you.

Abandoned mines and quarries in Southern Québec

In order to successfully rehabilitate all abandoned mining sites in Québec, it is necessary to obtain as much information on these openings as possible. A general compilation will give us a precise portrait of the situation so that legal measures can be taken to ensure public safety and protection of the environment at the very least. Of course, with the increasing scarcity of land because of demographic and legal constraints (Bill 90 deals with the protection of agricultural land),many of these sites will eventually be required for urban, agricultural or recreational uses.

Table 1 shows the number of quarries and mines (open-pit and underground) that were active, abandoned or intermittently in April 1982. "Intermittent" quarries are characteristic of the dimension stone industry for the pit is generally flooded between contracts. On the other hand, mines where extraction ceases for several months so that stocks may be liquidated are considered active. In the study area, 317 sites have been identified in the literature[1] ; this figure is thought to be precise. Sixty sites are still unvisited or have not been precisely located and are all very old underground workings for the most part. As many as 25 of these unlocated openings have presumebly been filled and reclaimed by nature since they date back to the 1850's and 1860's.

Since there is a direct relation between rehabilitation and proximity to urban settlements, thelocation of the excavations need to be known; these have been plotted in table 2. As we can see, almost 50% of the abandoned openings are situated in farming areas. In general, those sites are visible from a good distance if you are walking across the site but some still present a certain danger. Holes in wooded areas (42) are certainly the most dangerous since they are quite invisible and unexpected. Their relative remoteness gives them low

1-mostly geologic reports and rock and mineral guides for collectors-see SABINA (1975a and 1975b)

Table 1 : Active and abandoned mines and quarries in Southern Québec

	Montreal	Trois-Rivières	Québec	Sherbrooke	Thetford	Total
abandoned quarries	78	21	21	36	22	178
active quarries	45	14	12	21	16	108
intermittent quarries	2	0	1	2	1	6
Abandoned mines (open-pit)	1	0	1	8	25	35
Active mines (open-pit)	0	0	0	0	9	9
Abandoned mines (underground)[1]	0	0	0	31	13	44
Active mines (underground)[1]	0	0	0	1	0	1
no data-abandoned	0	1	0	42	17	60
Total active sites	47	14	13	24	26	124
Total abandoned sites	79	22	22	117	77	317
Total-sites	126	36	35	141	103	441

1-Abandoned or active underground mines with surface excavations have been compiled with the open-pit sites.

Table 2 : Location of abandoned sites in Southern Québec

	Montreal	Trois-Rivières	Québec	Sherbrooke	Thetford	Total
Urban	24	6	6	3	0	39
Urban fringe	7	4	2	8	6	27
Rural-farming land	48	11	14	38	38	149
Rural-wooded land	0	0	0	26	16	42
no data	0	1	0	42	17	60
Total	79	22	22	117	77	317

priority in rehabilitation and safety schemes which adds to the potential risk of accidents for a long period.

In urban and urban fringe areas, pressures from local residents will eventually lead to the implementation of primary safety measures (capping or fencing) and/or rehabilitation.

More precise information is needed to locate and describe the sites of old mines and quarries. Table 3 lists the adjacent land use of these openings. As we can see, agriculture (and related open-land) is dominant with 124 sites followed by wooded lands with 45 and residential with 39. Adjacent land-use is determined at the immediate periphery of the site and represents the dominant land use on the four sides of the mining area.

Concerning the sites themselves, it is of primary importance to study the present use being made of the land and if this use has been planned. Five categories has been retained (status) which are:

-reclaimed area : sites that have been improved by the use of heavy machinery and then returned to forest or agricultural land use. Only 6 sites correspond to this definition.

-reclaimed naturally : sites that have returned naturally to a state of forest or near-forest. 28 such sites have been identified.

-rehabilitated area : sites that have been improved and converted to planned secondary uses. 18 sites fit this definition.

-simply occupied area : sites that have not been improved but which are nevertheless being used. 13 sites fall into this category.

-backfilled excavations : excavations that have been filled with rubbish, earth, rock, tailings or other unwanted material without any improvement of the land around and over it. 10 sites fall into this category.

The second section of table 4 gives the specific use of the site regardless of the status. These data are particularly interesting since they show the present uses and likely vocations of the abandoned sites. This is especially true since there is no well established policy of reclamation or rehabilitation in Québec and excavations (and especially open-pits) are often left as they are; there are 116 sites with no specific use. In addition, 86 of the excavations are now either lakes or water-filled to some degree. Because of the flat quarry floor, some are used for industrial purposes, for sanitary landfills or as snow dumps.

Table 3 : Land use adjacent to the abandoned sites in Southern Québec

	Montreal	Trois-Rivières	Québec	Sherbrooke	Thetford	Total
Urban						
(multiple uses)	7	0	0	1	0	8
residential	15	7	8	7	2	39
industrial	7	1	0	0	0	8
recreation	1	0	0	3	3	7
mining	5	6	0	2	9	22
agriculture	42	7	12	36	27	124
wooded areas	0	0	2	25	18	45
no data	2	1	0	43	18	64
Total	79	22	22	117	77	317

Table 4 : Status and uses of abandoned sites in Southern Québec

Status	Montreal	Trois-Rivières	Québec	Sherbrooke	Thetford	Total
reclaimed	4	0	1	1	0	6
reclaimed naturally	11	3	4	7	3	28
rehabilitated	11	4	0	2	1	18
simply occupied	7	1	2	2	1	13
backfilled	5	0	0	2	3	10
no status[1]	41	14	15	103	69	242
Total	79	22	22	117	77	317
Uses						
Urban(multiple uses)	1	0	0	0	0	1
residential	5	0	1	1	0	7
industrial	2	0	3	1	0	6
reservoir	0	1	0	1	1	3
sanitary landfill	4	0	0	0	0	4
snow dump	1	0	0	0	0	1
mining	1	0	0	0	1	2
recreation	11	1	0	0	2	14
lakes & marinas	25	11	3	26	21	86
wooded area	1	0	0	6	1	8
agricultural	0	1	0	1	0	2
no use	23	7	15	38	33	116
no data	5	1	0	43	18	67
Total	79	22	22	117	77	317

1-including no data sites.

Certain new uses,for example residential and recreational affectations, are related to urban development and can be explained by local needs for urban space. In these cases, topographical problems have been overcome by backfilling; construction then takes place over the filled-in hole. But in most cases and even in urban areas, basic economics will preclude those radical and costly schemes. Instead, real savings can be achieved if the proposed use is "fitted" into the excavation as it is.

Table 5 illustrates the forms of the open-pit mines and quarries at the close of the mining operations. Most openings are of form A which is a hole below the horizon line. Form B is an excavation perched on the side of a hill with a flat entrance level floor. Form C is a derivate of form B in which the quarry floor has been excavated downwards.

Reclamation and rehablitation schemes must also take into account the dimensions of the excavations. The area covered is of great interest, especially when we wnat to select possible uses and prepare detailed estimates of the costs involved. Table 6 shows the areas of all excavations surveyed including shafts and adits which are included in the first class. Six classes have shown to be quite satisfactory even if in class 6 verylarge excavations including holes up to 126 hectares are classified with "smaller" excavations of 6, 7 or 8 hectares.

Another factor considered in reclamation is the rock or mineral that have been mined (table 7). In the southern part of Québec, limestone and dolomite quarries clearly dominate with 84 abandoned sites, followed quite behind by the sandstone quarries. The mining of copper and asbestos fibres accounts for 36 and 22 sites respectively. It is interesting to note that the "no data" sites are in large part copper and chromite mines.

Dangerous sites within the survey area

Planners, agronomists and geologists involved in reclamation work today should recognize that the first and most essential step is to render the openings safe. In the mining industry, the necessary safety measures are generally taken by the mining engineers and the mine owners but in the case of abandoned mines and quarries, such work must be accomplished by the professionnal invloved in the reclamation of the site. In the past, operators were not required to cap or fence abandoned excavations; these openings are still unsafe today and should be considered a matter of urgent concern by the provincials governments.

Table 5 : Forms of the open-pit excavations

	Montreal	Trois-Rivières	Québec	Sherbrooke	Thetford	Total
A- 	61	20	6	32	28	147
B- 	8	0	12	4	12	36
C- 	1	0	3	2	3	9
D- others	1	0	1	5	0	7
no data	8	1	0	1	4	14
Total	79	21	22	44	47	213

Table 6 : Areas of the abandoned excavations in Southern Québec

	Montreal	Trois-Rivières	Québec	Sherbrooke	Thetford	Total
< 0.1[1] ha.	2	2	2	40	20	66
0.11 to 0.5 ha.	11	4	3	12	11	41
0.51 to 1.0 ha.	12	1	7	4	3	27
1.1 to 3.0 ha.	10	9	8	7	7	41
3.1 to 6.0 ha.	12	0	2	4	4	22
> 6.1 ha.	14	1	0	2	7	24
no data	18	5	0	48	25	96
Total	79	22	22	117	77	317

1-alla shafts and adits are included in this category.

The author is also interested by the type of danger represented by these openings. Four initial classes were chosen : possible falls, possible drowning, possible collapse of buildings and possible collapse of portals and cave-ins. Table 8 shows the dangerous and safe abandoned sites; since no evidence of possible collapse of roofs or portals was recorded, this class was eliminated. As we can see, on 81 sites there is the danger of falling into an opening; the latter are mainly shafts, raises, chimneys, small pits, deep trenches and larger hidden open-pits. The degree of danger is not proportional to the depth of the holes; generally speaking and taking into account the physical aspects of the opening, the danger is considered real once the depth exceeds 3 meters. A second factor of prime importance is the immediate surroundings of this opening. A hidden wooded mining area is certainly very dangerous since trees and shrubs have grown back around the openings; very often, those holes (shafts) will be discovered at the last second, three or four meters from the pit itself. An unaware visitor would certainly be in real danger and particularly if he is travelling fast (trail bikes, bicycles, horse, snowmobile or on skis).

The danger of falling also increases or decreases with the season. In the summer when foliage is at a maximum, and when the ground is covered with plants such as ferns, the danger is the greatest. In winter, foliage is absent but the ground is covered with snow and ice that partly or totaly hides the smaller pits from view. In spring and autumn, when foliage is generally absent or not well developed, the holes are visible from further away but the danger is still there.

Generally speaking, the open pit excavations which were surveyed are surrounded by poor quality fences between 1 and 2 meters high, without barbed wire at the top, and poorly maintained. But most of the open-pits that present a real danger of falling are not fenced at all.

Concerning the undergound mines, especially in the Thetford and Sherbrooke regions where they are most frequent, most of the shafts and adits visited were not capped or backfilled. Occasionaly, we found a low fence near the openings or at the entrance to the site and a faded "danger" sign.

Most of the openings, especially the open-cuts and small size underground access holes have been flooded and present a real danger of drowning. 36 excavations, including some of the 81 counted in the " falling " risk fall in this category. Most are open-pits that have subvertical to vertical walls that offer no grips and with depths greater than 5 meters of water. The deeper excavations are usually filled with water up to the water table which leaves 2 meter or more of wall before the surface is reached.

Table 7 : Rocks and minerals extracted

	Montreal	Trois-Rivières	Québec	Sherbrooke	Thetford	Total
Limestone[1]	44	21	5	11	3	84
Shale	5	0	4	0	0	9
Schist & gneiss	1	0	2	3	1	7
Slate	0	0	0	6	1	7
Sandstone	15	0	10	1	1	27
Marble	7	0	0	5	2	14
Intrusive rocks[2]	4	0	0	8	9	21
Volcanic rocks[3]	0	0	0	0	2	2
Talc	0	0	0	1	2	3
Mica	0	0	1	0	0	1
Quartz	0	0	0	2	0	2
Asbestos	0	0	0	1	21	22
Pyrite	0	0	0	1	3	4
Copper	0	0	0	30	6	36
Chromite	0	0	0	6	2	8
Others	3	0	0	0	5	8
no data	0	1	0	42	19	62
Total	79	22	22	117	77	317

1-and dolomite

2-granite and syenite

3-andesite and basalt

Table 8 : Dangerous and safe abandoned mines and quarries in Southern Québec

	Montreal	Trois-Rivières	Québec	Sherbrooke	Thetford	Total
Possible falls	14	3	4	34	26	81
Possible drowning	20	10	3	28	25	86
Possible collapse of old buildings ..	1	0	0	0	0	1
no danger	44	8	15	13	9	89
no data	0	1	0	42	17	60
Total	79	22	22	117	77	317

Those water bodies develop a thermocline which means that water is usually warmer in the first 2 to 3 meters and very cold in the lower part of the basin. Swimmers who are attracted to those artificial lakes are unfamiliar with this thermal stratification and occasionnaly fall victim to cardiac arrest or to cramps when they cross this thermocline. This situation may develop in one quarry but not in the next one, which means that research is still needed to determine the parameters and the periods during the year when such situation could develop. Of course, the danger of drowning is most acute in the summer when swimmers are frequently seen in abandoned quarries but the danger is all year round for possible falls in water-filled openings. An unexpected thaw in winter and in spring and autumn could mean that the ice cover of the pit might not support the weight of a man and evenless the weight of a snowmobile or 4X4 vehicle.

The possible collapse of old buildings is not a widespread danger. Of a dozen sites where abandoned buildings were seen next to the openings, only one was found to be of real danger. Demolition of these buildings should be undertaken while cleaning the sites of rubbish and unwanted wastes, which are usually seen in the areas.

Finally, 89 sites offered no specific danger. Those sites are either rehabilitated and reclaimed naturally or adequate safety measures have been taken or are not really needed. Some are not fenced at all but have topographical features that reduce greatly the possible risks of falling or drowning.

<u>Reclamation and safety- a prospective view</u>

This brief examination of the situation of abandoned and reclaimed mining sites in the southern part of Québec gives us valualble information on the work to be done if we want to eliminate all sources of danger and reclaim all abandoned mining sites within the next century. By intention, the environmental and esthetic aspects of reclamation were not treated as well as the problems associated with the revegetation of the tailings because of the limited time allowed. Also, this survey will be completed as soon as possible in order to determine the necessary steps that the government authorities should put forward.

The present legislation in Québec concerning mining and reclamation is inadequate to ensure the degree of public safety and environmental protection that is of prime concern in reclamation (BOIVIN,D.J.,1982). But my intention is not to lay the blame at any one individual's door. I think the situation can be explained by the short-sightedness of our past governments and by the absence of regulations concerning the abandonment and rehabilitation of the

sites at the end of the operation, regulations that exist today in both the quarrying and the mining industries.

In Québec, 1959 was the year when the inspectors of the "Ministère des Richesses Naturelles" began to insist on the capping or backfilling of shafts and adits. It is safe to say that all the mines abandoned before this date are not covered or fenced today. In addition, the slabs and fences laid out since 1959 have often deteriorated to such a point that the danger has reappered at least for a certain number of sites.

To conclude, it is believed that without any political will to ensure the safety of the population and the reclamation of these sites, and taking into account the present economic recession, these abandoned sites will remain as they are for many decades in the future. It is our responsability to insist that the authorities adopt adequate measures to overcome the obstacles that hinder reclamation and especially the legal constraints notably the retroactivity of present laws, responsibility of owner of surface or mining rights respectively,etc. A special law, similar to the "Pit and Quarry Control Act " of Ontario must be drafted urgently and is believed to be the fastest and most efficient way of eliminating these dangerous and wasted derelict lands (BOIVIN,D.J., 1982).

Thank you very much for your attention. If you have any questions, I will be glad to answer them.

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ESTABLISHING GRASS, SHRUBS AND TREES ON COMPLETED SANITARY LANDFILLS

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INTRODUCTION

As urban population continues to grow and landfills are closed, we can anticipate greater stimuli for converting former landfill sites into recreational areas. Communities may be persuaded to turn these former unused wastelands into parks, golf courses and nature centers. The advantages of converting former landfill sites into attractive recreational areas are (a) inexpensive land acquisition, (b) proximity to urban centers (c) landfills can accommodate rolling landscapes which are frequently desirable for parks and golf courses, (d) value of land will increase after reclamation and (e) could provide a local recreational hunting ground.

The list of disadvantages for converting former landfills into parks is long. Frequently (a) soil cover is thin, (b) cover soil is compacted by the soil spreading equipment causing severe restriction of root growth, (c) soil nutrients and soil moisture levels are quite low, (d) irrigation requirements are greater on landfill areas than on nonlandfill areas, (e) surface irrigation is difficult because of uneven refuse settlement, (f) settlement causes breakage of permanent irrigation and other underground service lines, (g) settlement will cause undulating fairways and greens on golf courses, (h) landfill gases may migrate into soil cover and kill plants, (i) soil oxygen may be forced out of the soil atmosphere by landfill gases and asphyxiate roots, (j) several heavy metals become more available to plants under anaerobic soil conditions and this can lead to poor plant growth and (k) trees (plants) tend to produce shallower roots (1).

Despite the apparent difficulties encountered in vegetating completed landfills, they have been overcome in a few instances within the United States. At these sites, those charged with designing and maintaining the vegetation project were aware of several of the obstacles. However, the majority of reclamation programs were designed by individuals who were unaware of the special problems associated with growing plants on completed dump sites.

This paper will provide guidelines for planting grass, trees and shrubs on a completed landfill. Most recommendations are based on the results of a six-year research grant funded by the Municipal Environmental Research Laboratory of the USEPA. A more comprehensive detailed manuscript is being developed for publication by the Environmental Protection Agency and should be available from EPA in Cincinnati or NTIS by the spring of 1983.

GAS GENERATION

The gases of anaerobic decomposition (primarily methane-CH_4 and carbon dioxide-CO_2) may migrate from the refuse layers into the cover soil and/or

into adjacent property (1,2). Gas contamination of the cover soil will not be uniform over the entire landfill site. Some areas will contain relatively high carbon dioxide (>25%) and methane (>40%) concentration (consequently low oxygen (<2%) content); whereas, other areas will be influenced very little by the underlying refuse material. These gases are best controlled by specific activities which should take place soon after the final layer of refuse is spread. However it may be best to allow refuse to settle awhile before control measures are installed.

GAS BARRIERS

There is no doubt that combustible gases must be kept from the root system in order for vegetation to survive (2). The provisions which will ultimately lead to a desirable root gas environment are likely to function best and cost less if they are installed prior to spreading the final cover material. These precautions should consist of the selection of a barrier material which is both relatively gas-impermeable, flexible and durable (should last for decades and withstand settlement). This gas barrier material should be placed over the final layer of refuse. This should keep much of the gas away from the cover soil which will be placed over the barrier.

If the gas is prevented from traveling vertically into the cover soil, it is likely to move laterally into adjacent properties. In this case, gas migration control measures should be installed around the periphery of the refuse fill. There are a variety of systems currently available (3).

Impervious liners used to control gas flow include plastic, rubber or similar synthetic membrane, natural clay and asphalt. Polyvinylchloride (PVC) has been the most widely used synthetic membrane, because it can control gases, has a high resistance to deterioration and is relatively inexpensive. However, PVC will reportedly lose its plasticizer (and perhaps its effectiveness) after a few decades. Hypalon^R, chlorinated polyethylene (CPE) and other membranes are more attractive where the synthetic material must maintain its performance standard for fifty-plus years. Natural soil barriers, such as water saturated clay or bentinite lagoon liners, may be highly effective if kept saturated, otherwise cracks will develop as the material dries and the refuse settles. Dry clay or bentinite is not an effective barrier.

There are two approaches to installing barriers. One is to cover the entire landfill with the material and the other is to place the barrier only in areas where deeper rooted vegetation (trees and shrubs) will be planted. Settlement is likely to cause cracks or breaks in the seals used in either of these approaches allowing gas to penetrate the cover soil.

An alternate method of gas exclusion may consist of the mounding of soil in specific areas where deeper rooted vegetation is to be planted. The mound may be underlain by a clay layer or a membrane at least 20 mil thick. At least 90 cm of soil should be spread over the barrier in areas where trees will be planted.

COVER SOIL

Depth

Numerous investigators (4, 5, 6) report that 60-80% of tree root volume can be found in the top 20 cm of mineral soil. The remaining portion is located at varying depths (from 30-90 cm+) depending on species and soil characteristics. Although a 30 cm landfill cover soil may accomodate a good portion of the root volume, it would dry out quickly during seasonal dry spells. Because of the excessive cost of covering the entire landfill with deep rich soil, consider spreading 90 cm only in those areas where trees are to be planted. This need not be composed entirely of topsoil, however; topsoil should be incorporated into the top 20 cm since this is where most of the feeder roots will be growing. At least 60 cm should be spread in areas where trees will not be planted since this complies with government regulations.

Texture

The texture of cover material will necessarily vary depending on availability. Generally, if no gas barrier has been installed, it is best to first spread soil with a high clay content and cover with a highly organic soil. The deepest organic soil should be placed in areas where trees will be situated, such as a parking lot island, a clump planting on a golf course, or any other group planting. Where a membrane gas barrier has been installed, sand should first be spread on top of the barrier followed by a loamy textured soil capable of supporting plant growth. The sand will serve as a drain so that water will not accumulate above the membrane and asphyxiate roots growing in this region. The sand also serves as a protective buffer between the tires or tracks of soil spreading equipment and the membrane.

Spreading

One should strive for a soil bulk density of 1.3 to 1.5 g/cc in a loam soil. A slightly higher density (1.6 g/cc) can generally be tolerated in a coarser soil. Cover soil is frequently deposited with an earthscraper. A layer of soil loosely spread from the scraper box may be compacted to half its original thickness by the passage over it of the rear wheels of the machine. Bulk densities in the order of 2.0 g/cm^3 in the wheelings are common compared with 1.2 g/cm^3 in the loosely spread soil (7) between the wheels. The end product of such spreading is a series of horizontal layers of more or less loose soil, with intervening compacted zones. These have been shown to restrict penetration by roots and the downward movement of water.

Avoiding or eliminating these compacted layers is vital to good soil reclamation. Soil should be spread only when it is dry, using alternative earth moving machinery to the normal earthscraper. Dragline excavators, bucket-wheel excavators, forward acting shovels and dumper trucks have been proposed but entail costs considerably higher than earthscrapers (8). Until we are prepared to accept these greater costs, earthscrapers will continue to be the most common tool used and means will have to be used for overcoming the compaction they create.

If several different soils are to be used in the final cover material

over the clay layer, they should be mixed together and spread as a unit, not in separate layers. Spreading soil in a thick layer will promote less overall compaction than spreading in several thin layers. Water movement and root growth will also be less restricted by the former method.

If soil must be spread in the conventional manner and bulk densities are above 1.7-1.8 g/cm^3, consider the following procedures designed to promote better root growth and soil water flow thereby ultimately providing a more successful reclamation project.

Preparing Compacted Soil for Plant Growth

The destruction of the compacted layers by means of sub-soiling or deep-tine ripping after the full thickness of soil cover has been placed is not usually completely effective because the available machinery cannot draw the tines deep enough or close enough together or the operation has been performed at the wrong soil moisture (8). There has been some success with ripping each layer after it is spread and with the use of specially designed subsoilers. A vibrating subsoiler and the double-digger may be useful, but they are currently only being tested for their usefulness in aiding landfill reclamation projects (9).

Soil structure can also be improved by establishing a grass or ground cover (e.g. tall fescue, rye grass, crown vetch) for several years before planting trees and shrubs. The processes of freezing and thawing, rainfall, earthworm activity, soil and insect activities, percolation and leaching will also help increase soil porosity and promote more desirable soil physical properties. This process of reestablishing the network of pores and fissures by which the soil drains, may take many years. Thorud and Frissell (10) report that after artificially compacting a sandy loam from 1.14 to 1.45 g/cc bulk density in the 0- 7.5 cm depth, recovery to original bulk density occurred within 8.5 years but no recovery was recorded for deeper layers.

Organic amendments are beneficial to the physical, chemical and biological properties of most cover soil. Addition of these materials will reduce the soil strength and increase water infiltration and retention. Some organic materials provide an energy source and improve the environment for beneficial soil microorganisms and other fauna. These organic materials may include humus, peat moss, manure, crop residues, composted sewage sludge or refuse compost.

Fertilizing and Liming

Soil tests for pH and the major nutrients: nitrogen, potassium, and phosphorus; soil conductivity and, where possible, for the other macro and micro-nutrients should be made in a number of areas within the proposed tree planting site. Samples should be collected from a 0 to 20 cm deep soil column over a large area in a cross or zig-zag pattern. Heterogeneity in soil can be overcome by collecting several (5) subsamples over an area and pooling these to form a single composite sample. Replicate composite samples should be collected at each location. For routine soil nutrient-level surveys, any of a number of soil auger types

may be used to obtain samples. The State University will help to interpret the results and make recommendations for the addition of fertilizer and/or lime. However, where trees and herbaceous species are seeded together, the rapid vigorous growth of the herbaceous vegetation in respon to fertilizer may suppress or prevent establishment of seeded trees.

Heavy Metals

Soils which contain high concentrations of zinc, copper, manganese, iron, cadmium or lead should not be used for cover material unless this situation can be corrected by increasing the pH to a level not exceeding 7.0. There are several publications which discuss metal contents of soil in relation to plant growth (11, 12).

Soil Moisture

Soil moisture content of landfill cover soil will be considerably low than the same soil on a nonlandfill area (13,2). The factors contributin to this include thin cover soil, low organic matter content, lack of established capillary pore space, extreme micro-climates of most landfil higher leaf transpiration rates than in nonlandfill areas, and less infi tration of rain and irrigation water due to the highly compacted nature the soil and in some cases, sloping ground. Drought resistant tree and shrub species frequently seed themselves on completed landfills and can also draw more moisture from the soil at low moisture contents than drought sensitive species (14, 15).

Many different types of organic matter listed in a previous compaction section will increase water holding capacity of the soil. Mulching with wood chips, bark, saw dust, grass clippings or plant debris can help control evapotranspiration by reducing soil temperatures, weed growth and evaporation from the soil surface. More irrigation water will be required to maintain plantings on a landfill than on a nonlandfill area even if these policies are implemented. An above-ground irrigation system will require less maintenance than an in-the-ground system which will require continual maintenance because of breaks caused by settlemen

Erosion Control with Herbaceous Species

Mixtures of annual and perennial species are best suited for quickly stabilizing soil and protecting against erosion on disturbed land. The annual plants provide a quick temporary cover succeeded by a more permanent perennial species. Grasses and legumes should be selected on the basis of local climate and desired end use. Seeding rate recommendations should be followed carefully for the quick cover species because higher rates could produce dense stands that prevent or retard establishment of the permanent species. It is best to test many species on a closed porti of the landfill to determine which are best for reclaiming that particul site.

SELECTING TREE AND SHRUB MATERIAL

Slow-Growing vs. Rapid-Growing Species

There is evidence that slow growing trees are more tolerant to landfill conditions than rapidly growing species (6). Faster growing trees generally draw more moisture from the soil than slow growers and would, therefore, require more irrigation than the latter in order to maintain growth comparable to that on a nonlandfill area. However, if you are not concerned about how rapidly the trees will grow on the landfill compared to a nonlandfill area, then a faster growing tree may be more desirable, because it will generally provide a vegetative cover more quickly.

Small vs. Large Plant Material

Trees planted when small (1 m tall) showed significantly better growth on the landfill than those which were planted when larger than 2 m tall, regardless of species (6). Our data point out that this is related to the ability of a small tree to adapt its root system to the adverse environment in cover soil by producing roots closer to the surface (i.e. away from the higher landfill gas concentrations deeper in the soil). Roots of larger trees, on the other hand, start at a much deeper level and sometimes cannot develop adequate growth toward the surface before being killed by landfill gases. Our data (6) indicates that by the time the larger tree adjusts to the landfill by producing a shallow root system, the smaller specimens, which started with a shallow root system, can actually grow to the size of the larger trees and in some cases, surpass them. If trees taller than 1.5 m are necessary, plant them on a raised bed as to allow for shallow root development.

Volunteer Species

Although we have not specifically studied early successional volunteer tree species on landfills, they are generally very adaptable to poor soil conditions and are frequently found establishing themselves on complete landfills. Information on volunteer species can be found in several texts (16, 17).

Natural Rooting Depth

Tree and shrub species which enjoy a shallow root system were found in our studies to be significantly more adapted to landfill sites than specie requiring a much deeper root system (6,13,23). The deeper roots are subjected to higher concentrations of landfill gases and lower concentrations of O_2. Some species can avoid this adverse gas environment by producing a shallow root system, other species grow poorly because they are unable to produce shallow roots. Observations at the South Coast Botanical Garden in Palos Verdes, California, a former 87-acre landfill site also showed that shallow-rooted plants seldom were affected by landfill gases, but on some occasions there had been root damage to the larger deeper-rooted trees and shrubs (1). Several texts showing natural rooting depth of woody species are available (16,17,18) but this information is based on crude observation and is very incomplete and therefore should be used with great care.

The fact that trees growing on landfills generally develop shallower roots than the same species growing off the landfill emphasizes the need for more frequent irrigation of landfill soils planted with woody vegetation than comparable nonlandfill areas. In our studies at the Edgeboro Landfill in New Jersey, species excavated for extensive root studies on the landfill had a significantly larger portion of their root system in the top soil layers than in the deeper layers. However, roots were much more evenly distributed vertically on trees growing in the nearby nonlandfill control area (13). Deep-rooted vegetation can grow well on a landfill only if landfill gas does not migrate into the cover soil where trees are growing and provided adequate soil (90 cm or greater) is supplied to the area.

Flood Tolerance

Our field data indicates that the changes produced in landfill covers by gases are similar to those imposed by the flooding of soils; however, the high moisture content is lacking in the landfill cover soil. Therefore, species which are resistant to "wet feet" (flooding) conditions may do well on landfills only if they are supplied with adequate water. Dry site species should be planted if water will not be readily available on the site.

Size of Plants at Maturity

Another factor to consider when selecting species for landfills is size of the tree at maturity. If the cover soil is relatively shallow (30-60 cm), then choose a tree which remains relatively small at maturity or risk tree toppling during high velocity wind storms due to shallow rootedness. If a deeper soil cover is used (1 m) then the risk of windthrow will be diminished because the root system has adequate soil space to produce anchor roots, provided landfill gases are kept out of the cover soil and the trees are irrigated. There are a number of publications available which contain information on tree height at maturity (17, 18, 19). Local nurseries, landscape architects and the State University can provide information for your particular locality.

Mycorrhizal Fungi

Mycorrhizal fungi in association with plant roots have been shown to greatly increase water and nutrient uptake by plants (20). This symbiotic association has been successfully used in coal strip-mine reclamation. Mycorrhizae may also aid in successfully establishing vegetation on completed dump sites since landfill cover soil frequently has a poor capacity for holding nutrients and water. Spore and mycelium inoculated soil has been tested for its ability to promote mycorrhizae development o trees in landfill cover soil. Results indicate that both forms of inoculation may be viable alternatives to planting trees in uninoculated soil (21). More study is needed in this area to better understand this relationship.

Pathological (Disease & Insect) Considerations

The selection of trees, shrubs or grasses should always be based on the ability of the species to withstand attack by damaging diseases or insects common to the given area. The State University can frequently provide valuable practical information concerning disease and insect-resistant plant material, optimum planting time, proper fertilization and other soil amendments critical to a pest control program.

Gas Extraction

Extracting gas from within the refuse fill by an induced exhaust system, as is currently being practiced in several states and abroad, should aid in plant growth by reducing the quantity and pressure of the landfill gas generated in the refuse. Extraction should be compatible with establishing vegetation on completed landfills. However, commercial extraction operations are likely to end before the generation of gas has ceased, because extraction will become economically unfeasible after a number of years of operation. Even so, it may be desirable to continue running the extraction equipment, since there is likely to be enough biodegradable material left in the refuse to generate gases in concentrations harmful to plant growth. Undoubtedly the plants have established themselves in soil which most likely had a very low landfill gas content during operation of extraction equipment, and if the pumps are turned off, the gas content in the root zone environment may increase sufficiently to cause plant death.

Conclusion

Landfills are being converted into parks, golf courses and recreation areas. It is our duty to disseminate what we know to the engineers and planners and convince them that there is more to reclamation than haphazard guess work. We certainly do not know all the answers yet but we have begun to understand the complexity of developing on completed landfills.

LOCATING AREAS UNSUITED FOR VEGETATION

One or more years prior to the time when trees are to be planted, a ground cover should be seeded first to provide protection against erosion as well as to indicate where it would not be advisable to plant deep-rooted plants. Suggested annuals for the eastern United States include weeping lovegrass, Kentucky bluegrass and perennial rye grass. These should be seeded with perennials such as tall fescue, birdsfoot trefoil or crown vetch. The ideal time for seeding such disturbed areas is in the early spring or fall. In most cases, if the grass cover with its shallow roots dies or fails to germinate because of the influx of gases from the landfill, one can be certain that other deeper-rooted vegetation will not thrive either at these locations.

The easiest and quickest method of locating areas which are unsuited for plant growth is to observe existing vegetation patterns. The carbon dioxide (CO_2) and CH_4 concentrations are likely to be high and limiting to plant establishment in areas where the soil appears thin or the refuse is exposed. As a general rule, one should avoid planting trees and shrubs in areas which are devoid of ground cover.

Poor soil conditions for tree growth may be encountered even in places where grasses and other ground covers are thriving. Anaerobic soil or soil high in CO_2 or low in O_2 concentration may be present in the tree root zone which usually extends below the root zone of grasses. Table 1 points out several differences between aerobic soil which is likely to support tree growth and anaerobic soil. Even though an area has been chosen based on the above criteria for a planting location, differential settlement and varying gas production rates may cause gases to channel into a portion of the cover soil previously uncontaminated and kill existing plant material.

Table 1. Guide for Evaluation of Landfill Soil Gas Problem

Characteristic	Anaerobic soil	Aerobic healthy soil
odor	septic	pleasant
color	darker	lighter
moisture content	higher	lower
friability	poor	good
temperature	higher	lower

Refuse and soil settlement, caused by loss of refuse material through decomposition, will create an undulating surface causing water to pond in low spots during rainy and/or irrigation periods. Vegetation in flooded areas may eventually die if water remains for extended periods; whereas, plants on the unsettled higher areas may suffer from drought. Avoid planting in such low spots.

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EFFECTS OF PIG MANURE ON SOIL FERTILITY

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ABSTRACT

The disposal of pig manure presents a major problem in agriculture. Spreading it over land surfaces is one of the simplest solutions. In this way it will also provide nutrients to future crops. However, optimum and maximum tolerated amounts are not exactly known. In the present investigation the effect of pig manure applied in the concentrations of 0, 28, 56 and 112 t/ha was studied on three soil types: a silty clay (Kamouraska), a sandy clay loam (Janvier) and a sandy loam (St-Jude). The study involved the influence of the manure on the germination and growth of corn and millet and its effect on various physiological groups of soil microbes active in the carbon and nitrogen cycles such as starch decomposers, ammonifiers and nitrifying organisms.

Effects of pig manure on soil fertility

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The disposal of pig manure presents a major problem in agriculture. Using it as soil amendment is one of the simplest solutions (Dubé and Côté 1978). In this way it will also provide nutrients to future crops. (Atkinson et al. 1951; Mathers and Goss 1979; Miller and MacKenzie 1978). However, optimum and maximum tolerated amounts are not exactly known. The objective of the present study was to compare in 3 different soils the effects of the pig manure applied at concentrations up to 112 t/ha on the yields of corn and timothy.

Materials and Methods

The experiment was conducted in a greenhouse with 16 hours photoperiod and a temperature of 28°C. Three soils (table 1) and three concentrations of pig manure (28, 56 and 112 t/ha) were placed in a split- plot design with four replications. Two days after manure application, each pot (17 cm diameter) received either 10 seeds of the cultivar Acco Dc 108 of corn (_Zea mays_ L.) or 23 mg of seeds of the cultivar Climax of timothy (_Phleum pratense_ L.). Upon the emergence of corn, the plants were thinned to keep 5 healthy plants in each pot. The tops of the corn plants were harvested at the end of the 4th week and the experiment was repeated to study the residual effects. Tops of the timothy plants were harvested at the end of the 9th week and a second cutting was obtained 6 weeks later and was considered to reflect the residual effects of manure.

Plants were analysed as described by Ward and Johnston (1962) and statistical analysis were performed as described by Steel and Torrie (1960).

To study the effects of pig manure on seeds germination, fifty seeds of corn or timothy were placed on a blotting paper in a Petri dish containing the manure diluted in distilled water to give concentrations equivalent to 28, 56 or 112 t/ha. Each treatment was repeated four times. The petri dishes were incubated at dark and germination was recorded after 36 to 48 hours.

Results and discussion

The manure used in this study was sampled on a pig farm at St-Henri de Lévis, and it had the following composition:

pH 7.4; dry matter content 1.58%; P, 262.5 mg/ml; K, 2970 μg/ml; Mg, 37.6 μg/ml and total-N 5.64%.

At all concentrations used pig manure had no adverse effect on the germination of timothy seeds. The germination of corn seeds significantly decreased only in the presence of a manure concentration equivalent to 112 t/ha (table 2) presumably because of the NH_4^+ inhibiting effect at higher concentrations. In the three soils studied, the addition of pig manure significantly increased the dry matter yield of corn (table 3). In the Kamouraska and St-Jude soils, no difference was observed between yields obtained with the application of 28, 56 or 112 t/ha of manure. Corn grown on Janvier soil showed a better response to manure up to 56 t/ha. Addition of 112 t/ha of manure had a significant residual effect, which increased corn yield on the three soils studied (table 3). Increasing amount of manure applied to the soils increased the uptake of N, P, K and Mg by corn plants (table 4). In fact very significant correlations were observed between corn dry matter yields and the total content of the plants in N, P, K and Mg (table 7). The same correlations were observed with the second harvest obtained with P being an exception. No significant correlation was observed between yield of corn at the second harvest and the total content of the plants in P. (table 7). This might indicate that the residual P uptake by corn plants is affected by some unknown factors during the second harvest.

As with corn, addition of 112 t/ha of manure significantly increased the dry matter yield of timothy in the 3 soils studied at the first and second cuttings indicating also a significant residual effect (table 5). The total contents of timothy in N, P, K and Mg increased with the application of increasing amounts of manure (table 6). In fact significant correlations were observed between the yield of timothy and its total content of N, P, K and Mg (table 7).

The present work shows that the response of corn and timothy to the application of increasing amounts of manure will depend on the soil used. Also in some soils no significant yield increase was observed when 56 or 112 t/ha of manure was applied, the significant residual effect observed indicates that it is beneficial to apply a high concentration of manure in some soils assuming that the soil will permit its infiltration. In some soils with poor infiltrations injection of manure can be performed (Dubé and Côté 1978). We are presently performing a field trial to confirm the results of this study and to compare the fertility effect of manure with chemical fertilizers.

Acknowledgement.

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Table 1. Some characteristics of the three soils used in this study.

Soils	texture	pH	% organic matter	P kg/ha	K kg/ha	Mg kg/ha
Kamouraska	silty clay	7.7	3.1	148	287	381
Janvier	sandy clay loam	7.4	2.7	74	49	56
St-Jude	loamy sand	5.8	1.6	105	76	28

Table 2. Effect of pig manure on the germination of corn and timothy seeds.

Seeds	% germination			
	Manure t/ha			
	0	28	56	112
Corn	96.5 a	97.5 a	97.5 a b	88.5 b
Timothy	78 a	69.5 a	69 a	72.5 a

Means followed by the same letter are not significantly different at 5% probability level.

Table 3. Effects of pig manure on corn dry matter yields.

Soils	Manure t/ha	dry matter yields (g/pot) 1st harvest	2nd harvest Residual
Kamouraska	0	8.87	1.70
	28	9.70	2.42
	56	9.96	2.22
	112	10.48	3.19
Janvier	0	3.68	2.09
	28	4.93	2.32
	56	6.47	2.87
	112	6.40	3.56
St-Jude	0	2.49	1.32
	28	3.45	1.56
	56	3.90	1.50
	112	3.58	2.45
Statistical significance			
Soils		**	**
Manure		**	**
Soils x Manure		N.S.	N.S.

** Significant at 1% level; N.S. Non-significant

Lsd (0.05): 1st harvest Soils = 0.82
Manure = 0.65

2nd harvest Soils = 0.52
Manure = 0.58

Table 4. Effects of the application of manure on the total content of N, P, K and Mg in corn.

Soils	Manure t/ha	total content (mg/pot) 1st harvest N.	P.	K.	Mg.	2nd harvest N.	P.	K.	Mg.
Kamouraska	0	154.34	14.19	298.03	30.16	29.92	13.09	58.82	7.31
	28	193.03	13.58	297.79	36.86	38.24	17.67	72.84	9.92
	56	208.16	15.94	308.76	32.87	35.08	11.32	69.04	11.10
	112	285.06	17.82	387.76	37.73	48.81	19.14	107.18	12.76
Janvier	0	84.27	3.31	153.09	10.67	37.41	2.09	76.70	6.27
	28	89.73	4.44	138.04	17.26	33.64	2.55	63.57	8.58
	56	150.75	7.76	207.69	21.35	37.02	3.44	78.64	10.33
	112	170.88	8.96	261.76	23.04	53.40	3.56	110.00	12.10
St-Jude	0	45.07	1.49	88.15	10.96	18.61	1.72	33.40	7.66
	28	71.42	2.42	141.11	18.98	21.22	5.30	55.54	6.71
	56	90.48	3.12	175.11	14.82	20.55	1.65	45.75	4.95
	112	117.78	3.58	162.89	10.38	41.65	2.21	95.06	8.09

Table 5. Effects of pig manure on timothy dry matter yields.

Soils	Manure t/ha	dry matter yields (g/pot) 1st cutting	2nd cutting Residual
Kamouraska	0	6.99	4.41
	28	7.40	5.64
	56	6.78	5.72
	112	8.15	6.89
Janvier	0	0.27	0.69
	28	1.04	1.74
	56	2.23	2.57
	112	2.64	2.86
St-Jude	0	0.25	0.40
	28	1.42	1.73
	56	4.76	2.47
	112	6.30	3.65
Statistical significance			
Soils		**	**
Manure		**	**
Soils x Manure		**	N.S.

** Significant at 1% level; N.S. Non-significant

Lsd (0.05): 1st cutting: Soils = 0.62
Manure = 0.68

2nd cutting: Soils = 1.00
Manure = 0.68

Table 6. Effects of manure on total content of N, P, K and Mg in timothy.

Soils	Manure t/ha	total content (mg/pot) 1st cutting N	P	K	Mg	2nd cutting (Residual) N	P	K	Mg
Kamouraska	0	152.38	12.58	197.82	17.48	54.68	10.14	100.99	8.82
	28	199.80	13.32	232.36	20.72	81.78	11.28	146.64	11.84
	56	176.28	12.20	210.18	18.30	83.51	11.44	158.44	13.73
	112	234.72	13.86	274.66	20.38	128.15	12.40	188.10	14.47
Janvier	0	9.72	-	-	-	12.42	0.90	20.36	1.38
	28	35.15	1.46	36.92	2.39	28.01	1.91	41.59	3.13
	56	70.91	3.57	77.82	5.58	37.27	3.08	66.31	5.14
	112	94.51	5.02	107.98	7.39	45.47	3.72	78.36	6.86
St-Jude	0	4.38	-	-	-	-	0.32	9.12	1.00
	28	38.62	1.70	48.71	3.41	25.78	1.73	44.63	3.46
	56	105.20	5.71	143.75	12.38	27.42	2.96	64.96	5.19
	112	165.06	8.19	212.94	16.38	46.72	4.38	93.81	7.67

Table 7. Correlations between the yields of corn and timothy and the total plants contents of N, P, K and Mg.

yield g/pot		mg/pot N	P	K	Mg
Corn	1st harvest	0.92**	0.99**	0.95**	0.97**
	2nd harvest	0.95**	0.25 N.S.	0.93**	0.84**
Timothy	1st cutting	0.97**	0.97**	0.99**	0.99**
	2nd cutting	0.96**	0.97**	0.99**	0.99**

** Significant at 1% level; N.S. Non-significant.

RENATURALIZATION AT JAMES BAY

by

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ABSTRACT

Within the James Bay territory, construction of the various structures and installations involves the use of some 6,000 hectares (15,000 acres) of land for campsites, storage areas, work sites and borrow pits from which sand, gravel and moraine are extrated, since the overall area affected is impressive in size and the natural growth process in northern latitudes is slow, the direction de l'environnement will carry out a landscaping program which requires the production of ten million plants. After many years of studies and tests conducted to identify useful techniques of revegetation under the harsh conditions that prevail, shrub planting and sowing of graminease began in June 1979. The program is expected to be completed in 1987.

INTRODUCTION

The use of natural materials (such as moraine, sand, gravel and rockfill) for the construction of dikes and dams implies the excavation of vast areas. Thus, the construction of the 182 dikes and dams of the La Grande Complex entails moving 150 million cubic metres of fill, while providing housing for 17 000 people, building roads and opening storage and construction areas all required stripping additional areas.

At James Bay, the sand and gravel pits as well as all areas affected by the construction work are termed "affected sites". Whenever possible, these sites have been located in portions of the territory which are or will be flooded. However, major areas near the civil engineering works, totalling about 6000 hectares, have been excavated or cleared, and frequently compacted in the process.

Ecologically, the destruction of vegetation means a loss of biomass and habitats for particular animal species. Moreover, the physical modifications (clearing, filling and compacting), the poverty of the soils and the severity of the climate all slow down the process of recolonization by native plants. If no planting were undertaken, the majority of the sites would remain bare for decades.

That is why as early as 1975, even before the provincial regulations required users to restore sand and gravel pits, the Société d'énergie de la Baie James (SEBJ) Environment Department launched a program for restoring affected sites.

OBJECTIVES OF THE PROGRAM

The main objectives of restoration are:

- to initiate the renaturalization process in affected sites where it would otherwise be either too slow or totally absent;

- to improve the appearance of the areas near the permanent structures;

- to eliminate erosion in sites located near lakes or stream crossings and along permanent roads.

Furthermore, the varieties used for reconstituting the plant cover make it extremely likely that the treated zones will be visited by fauna in search of food and shelter.

RENATURALIZATION STUDY

In view of the scale of the restoration work involved, the techniques to be developed had to be both efficient and economical. Furthermore, the climatic and edaphic conditions of the James Bay territory made the transplanting of seedlings relatively risky.

For these reasons, the Environment Department put particular stress on studies to identify which species would be appropriate for restoration, and which growing and planting techniques would suit seedlings in a nordic environment, either adapting current methods to the conditions found in the territory or inventing new ones if necessary.

To follow these studies and the first tests of the restoration project, SEBJ decided to form a committee of renaturalization specialists, in collaboration with the Société de développement de la Baie James (SDBJ).

Table 1 shows a list of shrubby and arborescent species found appropriate for the restoration project. The main species selected were green alder, jack pine and willow. They can be grown in containers and their propagation techniques are well enough developed to make it possible to plan the production of more than one million seedlings. Reforestation tests of these varieties made it possible to identify the most favorable times for transplanting seedlings in northern Québec. Other experiments were used to define the most appropriate conditions for seeding graminaceous and leguminous plants.

TABLE 1

LIST OF SPECIES USED
IN RENATURALIZATION PROJECTS
IN THE LG 2 REGION

SPECIES ENGLISH NAME	LATIN NAME	METHOD OF REPRODUCTION	TYPES OF SOIL
Green alder	Alnus crispa "Mollis"	seeds	gravel-rocky soil
Jack pine	Pinus divaricata	seeds	fine-medium sand
Willow	Salix planifolia	cuttings	moraine and clay soils
Scrub birch	Betula glandulosa	seeds	humid moraine soils
Balsam poplar	Populus balsamifera	cuttings	humid soils
Quaking aspen	Populus tremuloides*	seeds	sandy soils
Black spruce	Picea mariana*	seeds	--
Tamarack	Larix laricina*	seeds	--

* Species under study and as yet little used.

INVENTORIES AND MASTER PLANS

Parallel to these studies, all disturbed sites within the Complex were inventoried and a master restoration plan was established for each jobsite, reflecting the future use of the various section of the territory. Thus, the restoration plan for the LG 2 region was prepared keeping in mind the high tourist potential of this region, which is the home of the largest and most powerful underground hydroelectric power station in North America. A tour route was established, and four levels or intensities of restoration work were defined, with classification depending on the proximity of the affected sites to the tourist sites:

Intensity 1: stops on the tour (lookouts, explanatory signs, etc.) and the immediate outskirts of the main structures (6% of the total area to be restored);

Intensity 2: affected sites along the edges of the tour route (20% of the total area to be restored);

Intensity 3: borrow banks located near the permanent roads (15% of the total area to be restored);

Intensity 4: all other sites remote from the tourist sectors (59% of the total area to be restored).

Intensive restoration was carried out on all category 1 and 2 sites, while planting covered only 25% and 10% of the total area of the category 3 and 4 sites, respectively. The transplanting of about two million plants, on nearly 1200 hectares, the seeding of grasses on 100 hectares, and the contruction and landscaping of five lookouts were the main projects in the restoration of the LG 2 region.

In the Eastmain-Opinaca diversion (EOL) region, except for the sites restored for future use by native residents (access ramps to the reservoir) and the sites located in the immediate vicinity of the permanent structures, all borrow banks and other affected areas were classified according to the likelihood of their natural recolonization. In sites where conditions were favorable to natural recolonization, planting densities were low, while in sites which had difficult conditions, they were higher, in order to accelerate the formation of an initial plant cover. In the EOL region, one million seedlings were planted on 670 hectares.

Although master plans have not yet been developed for the other jobsites, the total area damaged is known. This makes it possible to anticipate that 10,0 million seedlings will be needed to renaturalize all sites damaged by the construction of the La Grande Complex.

RESTORATION WORK

The restoration of the sites affected by construction occurs in two distinct steps:

- physical restoration and
- transplanting of seedlings.

Physical Restoration

Every contractor who has used land as a sand pit, gravel pit, construction area, etc. is responsible for its physical restoration. This includes general cleaning up, grading excessively steep slopes, loosening compacted surfaces, and spreading the organic matter or top soil which was pushed to the edge of the site when it was opened. This responsibility appears as part of the special conditions of the contracts with all contractors working in the James Bay territory.

At the end of the summer of 1979, the areas in the LG 2 region which had been used in the construction of the main dam and 31 dikes had all been cleaned and graded. The same was done in 1979 and 1980 on 670 hectares affected by construction in the Eastmain-Opinaca region and, in 1981 and 1982, on the LG 3 jobsite.

Transplanting of Seedlings

The seedlings used for renaturalization are obtained from three different sources (Table 2). The majority, two million seedlings in containers, were contracted from nurseries in Québec City, Montreal region, Val d'Or and Saint-Pascal that SEBJ was able to interest in this new type of greenhouse crop. The other seedlings in containers were grown in greenhouses belonging to the Montréal Botanical.

Gardens on the site of the 1980 Floralies exhibit. Seedlings grown in southern Québec are brought to the field for transplantation in trailer trucks under controled temperatures. The SEBJ Environment Department nursery, located near LG 2 , has specialized almost completely in growing willow cuttings. Nearly one-half million cuttings are prepared here every year.

Since 1979, the transplanting, planting, seeding, cleaning and look-out construction projects have been awarded to contractors through public tenders. All transplanting is done manually with pick shovels or Finnish planters. In the affected sites near the hydroelectric structures, seedlings and cuttings are planted 1,2 to 1,5 m apart. Elsewhere, islets or strips of vegetation are created at several points on a site being restored, taking care to avoid zones where overly severe conditions might threaten their survival. Moreover, wherever soil conditions allow, plantings are mixed, i.e. at least two species may be interplanted.

Additionally, hydraulic seeding of graminaceous and leguminous plants is used to provide a plant cover on the affected sites. However, the high cost of this method and the necessity of fertilizing the sites after they have been seeded restrict the applicability of this approach.

TABLE 2

ESTIMATE OF SEEDLING REQUIREMENTS FOR 1982 RESTORATION PROJECTS

PRODUCERS	SPECIES			
	Green Alder	Jack Pine	Willows	Others
Private Companies	1 800 000	100 000	150 000	100 000
Botaniçal Gardens (Montréal)	100 000	--	--	100 000
Lac Hélène (SEBJ)	-	--	400 000	---
TOTAL:	1 900 000	100 000	550 000	200 000
DISTRIBUTION:	70%	3%	20%	6%

SCHEDULE AND RESULTS

At the end of 1977, a pilot project was undertaken to improve the appearance of the sides of the road linking the La Grande airport to the LG 2 camp. Cleaning, grading, filling and seeding, along with transplanting 100 000 seedlings, made it possible to make this road more attractive.

In 1979, renaturalization and landscaping began at LG 2 with the transplanting of 250 000 seedlings and cuttings on the outskirts of the dam, the spillway and some borrow banks, while some twenty acres were seeded with graminaceous plants.

The results have been evaluated at regular intervals. One year after the first planting, the average survival rate of all species was 87% (Table 3). Average growth was low for most species, except the alder, whose annual growth of 7 to 14 cm can be considered normal. The survival rate of these seedlings was just as high in 1980, and, as expected, growth has been more substantial.

On the basis of these results, restoration was undertaken on a larger scale in 1980. More than 1,5 million seedlings were grown for use in the renaturalization process. Nearly 400 000 seedlings and cuttings were transplanted at LG 2 and more than 800 000 in the Eastmain-Opinaca region. Moreover, at LG 2, grass was seeded on more than 20 hectares and four lookouts were built and landscaped.

Restoration was completed in the EOL region in 1981. During summer 1981, a total 1,5 million seedlings were used for renaturalization by landcaping companies and a native-owned company, in the EOL region, at LG 2 and on the road linking LG 2 and LG 3.

Restoration will be completed at LG 2 in 1982. The LG 3, LG 4 and Caniapiscau jobsites will be restored during the next five years.

TABLE 3

EVALUATION OF THE SURVIVAL AND INCREASE IN HEIGHT
OF SEEDINGS TRANSPLANTED IN 1978 and 1979

SPECIES	PRODUCERS	CONTAINERS	SURVIVAL % (Fall 1978)	SURVIVAL % (Spring 1979)	GROWTH (cm) (1978)
JACK PINE	LH	STY	93	92	2,1
	MTF	STY	80	93	2,2
	MTF	PAP	84	92	1,8
	MTF	RN	40	-	0
Average			84	93	2,0
GREEN ALDER	LH	SPT	93		13,5
	LH	SRN	81		15,6
	MTF	STY	85	97	7,2
	MTF	PAP	74	96	7,8
	MTF	STY-NOD	100		6,4
	MTF	PAP-NOD	72		5,7
Average			84		6,7
SCRUB BIRCH	LH	STY	85	98	2,2
	LH	PPT	94	-	3,7
	MTF	STY	93	93	2,9
	MTF	PAP	88	100	3,4
Average			90	97	2,9
WILLOW	LH (77)	BBD	88		2,2
	LH	BF	100		1,6
	LH (78)	BBD	89	99	1,4
Average			92		1,9
BALSAM POPLAR	LH (77)	BBD	94		0,7
	LH (78)	BBD	83	95	0,8
Average			89		—

NOTE:

LH Lac Hélène
MTF Ministry of Lands and Forests

BF: leaf cutting
BBD: hard wood cutting
NOD: nodule
PAP paper pot
PPT peat pot

RN: naked roots
SPT: potted seedling
SRN: naked root seedling
STY: styrofoam block

CONCLUSION

Research conducted since 1975 and restoration work executed by SEBJ are typical of increasingly common efforts by Québec corporations and governmental agencies motivated by the conviction that technological development can only be justified if it respects social and ecological values. This concern is now reflected in provincial regulations which require contractors to restore the sand and gravel pits they have exploited.

The large-scale renaturalization of the La Grande Complex has made it a first in Québec, and experience acquired has made it possible to develop reforestation and reseeding techniques which may be applied in other regions of Québec.

THE LAND RECLAMATION PROGRAM OF THE REGIONAL MUNICIPALITY OF SUDBURY, ONTARIO

ACHIEVEMENTS SO FAR

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ABSTRACT

Through 5 years (1978-82) of student summer work program over 1500 hectares of acid, metal contaminated land has been reclaimed using soil amelioration and commercial grass seed mixtures. Although the vegetation cover is self sustaining the species composition has changed with time by invasion of herbs and woody species, particularly _Populus tremuloides_, _Salix_ spp. and _Betula papyrifera_. Deliberate introductions of woody species have proved successful. Changes in soil chemical conditions are reviewed.

RECLAMATION ASPECTS OF COAL ASH DISPOSAL

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RECLAMATION ASPECTS OF COAL ASH DISPOSAL

by

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ABSTRACT

Coal ash is produced in large quantities by Alberta's power plants. Various methods are available for its disposal or utilization. This paper discusses coal ash which is disposed on or near the surface and thus becomes a factor in reclamation.

INTRODUCTION

In recent years some excellent studies in Alberta have looked at the properties and behavior of coal ash in the reclamation context. I performed absolutely none of the research. However, I recently prepared a workshop proceedings entitled "Coal Ash and Reclamation" which presents the aforementioned research in considerable detail. I would like to summarize these research results not as an expert but rather as a generalist. Most of the information will be cited according to the researcher while some information comes from my impressions garnered from the workshop discussions.

DISCUSSION

Presently in Alberta coal ash enters the reclamation scene either as a dormant ash disposal lagoon, as a capping over orphaned sodic mine spoil or, indirectly, as an element in the post-mining groundwater system.

The four coal-burning power plants in Alberta employ four different systems for ash disposal each with different implications for reclamation:

> <u>Milner Generating Station, Grande Cache</u>. A dry mixture of fly ash and bottom ash is hauled by truck to abandoned mine pits.

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Wabamun Generating Station, Wabamun. A slurry of fly and bottom ash is pumped ~~to~~ permanent lagoons.

Sundance Generating Station, Sundance. A dry mixture of fly and bottom ash is trucked to the pit floors of active mines and buried by successive spoiling.

Battle River Generating Station, Forestburg. Nearly all of the fly ash production is sold for cement manufacture leaving only bottom ash for disposal on orphaned mine spoils.

Physical and Chemical Properties. Fly ash and bottom ash differ significantly in many respects. Physically, bottom is coarse sandy to gravelly in texture and has a high affinity for water. Because it is permeable and porous it behaves somewhat like pumice and may have use in improving heavy clay soils.

Fly ash is largely silt sized with between 10 and 20% clay and 25-35% sand sized particles (Pluth et al. 1981). Fly ash is quite susceptible to wind and water erosion.

Bottom ash and fly ash both consist primarily of alumino-silicate glasses with fairly high levels (3 and 10% respectively of Fe and Ca) (Dudas, 1981). Many other elements are present in lower concentrations. Ashes from western coals usually have lower S, As, Cd, Co, Cr, Pb, Sb and Zn levels than their eastern U.S. counterparts. Also, western coals have higher B concentrations (Abernathy, 1969; Natusch et al. 1975).

When fly ash is leached with water Ca, B and Sr salts are readily dissolved. Dudas (1981) suggested this is due to adsorption of these salts on the surface of the fly ash particle. Generally, fly ash yields more Al, B, Ca, Co, Cu, K, Mg, Na, Sr and Zn upon leaching than bottom ash (McCoy et al. 1981). It is important, however, to stress that ashes vary from site to site. For example, ash produced by the Milner Station at Grande Cache has less Ca, Na, Sr and Ba and more K, Cu, V, Zn, Ni and P than ash from the plains power plants (McCoy et al. 1981).

Weathering Behavior. Alkaline salts are rapidly leached from fly ash in large

quantities causing a sharp rise in pore water pH. Dudas (1981) studied the leaching behavior of fly ash over a two year period and indicated that the initial activity of fly ash was due to dissolution of CaO, Na_2SO_4, $CaSO_4$, $CaCO_3$ and $NaBO_2$. Hydrolysis by dissolved CaO was implicated as the primary agent in promoting alkalinity. However, with the loss of admixed and adsorbed salts another weathering process occurs in which the glassy particles are slowly dissolved. This process yields constant, low levels of elements found within the glassy matrix and heavy metals such as Cd, Cu, Cr, Hg, Pb and Zn are, under neutral to alkaline (and oxidizing) conditions, mobilized at only slight to negligible levels (Dudas, 1981).

A similar long-term leaching study has not been conducted on bottom ash but the data of McCoy et al. (1981) suggest that bottom ash would, over the short and long-term, weather much more slowly than fly ash. Relative to fly ash bottom ash seems fairly innocuous.

Environmental Impacts. Perhaps the most common concern with fly ash disposal is dust pollution. This is a localized problem and can be corrected by covering or otherwise vegetating the ash surface. Wind-blown ash deposits may also degrade surrounding soils. A large set of ash lagoons for a typical power plant may ultimately cover 400 ha to a depth of about 20 m. This would represent a sizeable withdrawal of land from other potential uses unless revegetated. Also, groundwater contaminants may leach from lagoons or from mine pit disposal sites.

The effects of ash leachates on groundwater are not well understood. Observations suggest that the physical characteristics of disposed ash strongly influence whether groundwater will percolate through it or go around it. For example, pure fly ash if it is pozzolanic will tend to exclude ground or surface water (Joshi, 1981). Bottom ash however is freely permeable and bottom ash/fly ash mixtures are also quite permeable. Most ash disposed in Alberta is either pure bottom ash or a bottom/fly ash mix. In a slurry-lagoon system lenses of nearly pure fly ash may develop but are not present to a great extent.

Under these conditions groundwater will tend to leach B and Ca from the ash. Little is known regarding the resulting concentrations of B in groundwater.

Boron is a concern because of its toxicity to plants even in low concentrations and would, for example, degrade irrigation water. Boron in domestic water is not considered a major health treat to humans or livestock at the levels likely to be encountered.

Fly and bottom ash both contain significant amounts of metals which in sufficient concentration could pose a problem in domestic water supplies. Under alkaline, oxidizing conditions these metals (excepting perhaps, Mo) would be nearly insoluble (Dudas, 1981). However, little is known regarding the release of metals from ash under the alkaline, reducing conditions common to prairie groundwater or whether mobilized metals would be fixed in bedrock clays. This area requires further study.

Revegetation of Ash Disposal Sites. Plants grown directly in fly ash or fly/bottom ash mixtures face two main problems: B toxicity and lack of nutrients. Hermesh (1981) reported available B levels on an ash lagoon at 6.9 to 30.5 ug/g. At these concentrations B is slightly to highly toxic to plants. Also, the ability of fly and bottom ash to supply or retain nutrients is very limited and annual imputs of fertilizer are required to maintain high levels of plant cover. However, 8 cm or more of minespoil, topsoil or manure have been reported (Hermesh, 1981) to provide a suitable growth medium when placed over ash.

High pH is another though less severe problem with ash. Fresh fly ash is more alkaline than fresh bottom ash (11.6 vs 8.6 McCoy et al. 1981). However, fly ash quickly becomes less alkaline upon weathering (Dudas, 1981). Hermesh (1981) reported a pH range of 7.0 to 8.5 on a dormant fly/bottom ash lagoon. The pH drop reflects a leaching of Ca and Na salts (Dudas, 1981).

Bottom ash disposal has been combined with sodic spoil amendment at the Vesta Mine near Forestburg, Alberta. Sodic spoil will support almost no useful plant growth so barren, pre-regulation sodic mine spoils are levelled and a layer of bottom ash is spread to serve as a plant growth medium. Initial results have been encouraging and productive forage crops have been established. However, erosion would be a problem on sloped areas in excess of 15°. Incorporation of

bottom ash with sodic spoil at a roughly 1:1 ratio did not prove successful in overcoming the adverse properties of sodic spoil (Natsukoshi, 1981).

CONCLUSIONS

Following is a summary of conclusions reached during the Coal Ash and Reclamation Workshop 29, 30 April, 1981:

Waste Disposal

1. What problems are likely to emerge in the large scale disposal of fly and bottom ash? Consider pit-fill, above and below water table storage, lagoon storage, effects of aerobic and anaerobic conditions.

   Several methods of ash disposal were discussed: 1) truck haulage to the pit floor and burial by spoil; 2) truck haulage to the dragline furrows in spoil and burial during spoil resloping; and, 3) truck haulage and spreading over resloped spoil. In addition to the truck haulage system, two means of wet (slurry) transport were discussed: 1) lagoon in unmined basin; and, 2) poldering.

   Pit floor disposal may cause spoil pile instability problems and in plains mines, ensures that the ash will be in contact with groundwater.

   Fly ash on the pit floor may act as a barrier to water movement. So, while limiting leaching of noxious materials, it will probably tend to seal itself and inhibit re-establishment of the water table on the pit floor. Even if the ash doesn't seal itself, since it would be deposited as a series of discontinuous bands perpendicular to water flow, it probably wouldn't be significant as an aquifer. While bottom ash would have good flow-through capabilities, there is some uncertainty regarding the release rate of metals under reducing and alkaline conditions. Most of the research so far has dealt with oxidizing acidic or oxidizing alkaline conditions and the later situation yields very low quantities of mobile metals.

   In general, it is more economical to slurry ash to a lagoon and concentrate it in a single depression of some kind. With interfurrow disposal

of ash, there is a possibility of differential setting and fly ash may act as a bar to downward movement of water. Poldering was considered uneconomical under present conditions.

2. How might the above problems be solved?

   1) By promoting secondary uses for ash, and 2) until we know more about the mobility of metals under reducing, alkaline conditons, it is probably best to keep ash out of the large aquifer systems, particularly in situations where we can't do anything about the material once it's in place (pit floor disposal).

3. What are the implications of dry versus slurry transport for reclamation?

   Considering economic factors and water quality, it was felt that wet haul lagoon disposal of a fly ash/bottom ash mixture is probably best because together, they are not likely to set up a cement-like structure and the question then becomes one of soil-building on the ash surface. In lagoon disposal of a fly/bottom ash mix boron will be a problem in the first five years although it looks like the boron eventually leaches out of the root zone. Apparently the metals present in ash do not concentrate in the plants. Lagoon ash has a low cation exchange capacity, a low nutrient level and questionable moisture holding capacity.

   Trafficability problems will exist unless soil or spoil is placed over the ash, otherwise access of machinery and livestock on the site would be limited. We also don't know the extent to which boron on metals enter the water table and dilute or concentrate. What effect would they have on groundwater quality? There is some information on leachates from laboratory studies but there is little hard data for field conditions.

<u>Use As An Amendment</u>

1. Is ash an effective amendment? Consider
   - sodic spoils
   - acidic spoils/soils

   There are three different types of areas where you could consider ash as

an amendment:

a) <u>In orphaned areas</u> where you no longer have topsoil or non-sodic material available, there is a possibility of using a bottom ash cap, or deep ripping to incorporate some of the ash to depth to permit penetration of water and roots.

b) <u>Use in soil reconstruction</u>. This would be an area with an identified shortage of suitable subsoil material. If only a thin solonetzic A horizon for example, is available it may be upgraded by using bottom ash to contribute calcium and lower bulk density thereby "stretching" available A horizon material.

Subcapping - where there is a shortage of buffering material between the sodic spoil and replaced topsoil there is a possibility that bottom ash can increase the root zone and enhance moisture holding capacity. It could help in drought periods.

c) <u>Use as a lime substitute for acid soils.</u> Fly ash would be a low grade liming material and may introduce boron toxicity problems.

2. How much ash is needed to amend sodic spoils?
It seems advisable to avoid mixing the bulk of added bottom ash into the spoil. Ash is unlikely to enhance sodic spoil at any concentration and should be left undiluted on the surface of the spoil.

3. Are special agricultural practices needed where ash is used as an amendment to sodic spoils? Consider:
- crop selection
- tillage practices

Yes, mainly trafficability. Crops will grow in leached ash, but there would be problems in seeding, cultivating and harvesting. Packing would enhance establishment in a lagoon, however, in an orphaned area where you are trying to make the best of a bad situation a forage crop requiring minimal traffic would be advisable. Cultivation or any other practice which would bring up sodic spoil from below should be avoided.

4. How should ash be hauled, applied and incorporated into spoil?
Dry haul is presently the only proven technique for applying ash for

amendment purposes and still trafficability is a problem. The possibility of poldering ash on levelled areas was raised. This might provide a deeper layer of ash for reconstructed soil. The trafficability problem precludes the use of most vehicles on ash.

Research Needs

a) Trafficability
b) Groundwater occlusion
c) Metal mobility under reducing alkaline conditions
d) Soil depth requirements over reclaimed ash lagoons
e) Use of ash in reclaiming orphaned spoil areas

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PRIME AGRICULTURAL LAND RESTORATION AFTER SURFACE COAL MINING IN MIDWESTERN USA, CHEMICAL AND NUTRITIONAL CONSIDERATIONS

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ABSTRACT

Resiliency of reconstructed prime agricultural land to seasonal perturbation and stress with respect to grain crop productivity, particularly from drought, remains a pressing but unanswered question. Evidence from soil tests and leaf tissue analyses of corn (Zea Mays L.) and soybeans (Glycine max (L.) Merr.) grown on reclaimed land show that a rapid weathering of newly exposed minerals produce toxicities and confound inherent nutrient deficiencies, thereby complicating management. These phenomena are especially important in the southern portion of the Illinois coal basin where high fertilizer rates are necessary for the elimination of nutrient deficiencies in the well-leached surface soils and deeper paleosol strata. Phosphorus deficiency is usually ephemeral, lasting a few months after soil replacement, but K deficiency is more persistent. Potassium and phosphorus deficiency were largely eliminated after 3 or 4 years with the judicious use of fertilizer where topsoil had been replaced, but deeper non-solum strata were less responsive to this standard nutrient build up strategy. These chemical problems have complicated the measurement of row-crop productivity in the Midwest by confounding the effect of nutrient and drought stress. Mechanisms behind these chemical problems, and methods analyzing and separating their influence from those of water and heat stress, will be discussed.

Prime Agricultural Land Restoration After Surface Coal Mining in Midwestern U.S.A., Chemical and Nutritional Considerations.

William S. Dancer

At the present time most surface coal mining operations in the state of Illinois are located in southwestern counties; Perry, Jackson, Randolph, St. Clair, and to a lesser extent in Williamson, Saline, and Gallatin counties. A second area of intensive surface coal mining is located further north in the western counties of Knox, Fulton, and Peoria (Treworgy et al. 1978). Overburden depths are between 100 and 150 feet, but there are some important differences between the overburden strata encountered in these two widely separated coal fields. The surface soils of the western coal field are highly fertile and productive, usually Mollisols which have developed in the deep loess and Pleistocene glacial till deposits of this area. Much more mature, well-leached and infertile "clay pan" Alfisols characterize the coal field of southern Illinois (Murray 1978). Similar coal members, Herron No. 6, and Harrisburg No. 5, are mined in both areas, but the shale, limestone, and sandstone encountered and their relative amounts are somewhat different because of differential rates of erosion and deposition during the Pennsylvanian period. In general, greater amounts of limestone and sandstone are encounted in the overburden of southern Illinois while the consolidated rock in western Illinois tends to be mostly shale with smaller amounts of limestone (Smith, 1958; Smith and Berggren 1960). Differences in the bedrock encountered in the overburden appear to be of little consequence because there are adequate amounts of alkaline overburden to neutralize any acidity resulting from pyrite oxidation. There is also a tendency to bury most of the unconsolidated rock strata with the Pleistocene loess and glacial till. This is advantageous for reclamation purposes, and the rock strata form a sturdy "buck wall" to stabilize the working pit and prevent slides. Overburden in western and southwestern Illinois tends to be alkaline (pH 7.3 - 8.1).

The major types of equipment used to strip overburden away to expose the coal at a given mine has a great influence on the composition of the resulting overburden, and upon how the solum (topsoil and subsoil) materials are handled. A large dragline can segregate the deeper Pennsylvanian rock strata from the superficial Pleistocene glacial till and loess than the more traditional stripping shovel; but this separation is automatically accomplished when a shovel and bucket-wheel excavator are used in tandom. The burial of potentially toxic (pyritic) strata, and the replacement of acceptable "rock free" material and topsoil at the surface are required by law (P.A. 81-1015, Art. IX) in Illinois. Therefore, topsoil and "rooting media" are hauled around the working pit to cover overburden cast in shovel operations not using a bucket-wheel excavator.

Table 1. Relative herbage yields† for three test crops with varying mixtures of subsoil (B_2) and the underlying loess (B_3-C_1 strata.

B_2/loess ratio	100/0	75/25	50/50	25/75	0/100
Perennial ryegrass	50a	76a	108b	136b	132b
Red clover	14a	20a	29ab	72c	42ab
Sudan grass	13a	23a	54b	95c	87c
Averages	26a	40a	64ab	101c	87b

†Yields expressed as a percentage of those observed on topsoil; and values followed by a different letter are significantly differing at the P = .95 level.

Table 2. Elemental composition† of 55 day-old corn plants grown on Weir subsoil, C_1-material and a mixture of these overburden materials at two fertility levels.

	Weir Subsoil		Mixture (50/50)		C_1-Material	
	NK	NKLP	NK	NKLP	NK	NKLP
Soil pH‡	4.4	6.8	4.6	6.3	5.4	6.4
			Macronutrients - %			
N	-	1.65a	2.08a	1.44a	1.86a	1.20a
P	0.09ab	0.13bc	0.09ab	0.18c	0.07a	0.36d
K	4.93a	2.74c	4.46ab	2.72c	3.82b	1.94d
Ca	0.72a	0.67ab	0.69a	0.62b	0.68a	0.55c
Mg	0.38a	0.62b	0.40a	0.56b	0.57b	0.60b
			Micronutrients, Metals - ppm			
Fe	110a	72a	71a	91a	44a	43a
Mn	214ab	156b	195ab	123b	271a	114b
Zn	44b	34cd	39bc	31cd	48a	30d
Cu	14a	6b	10ab	4b	11ab	6ab
Al	82a	21a	30a	11a	27a	28a
P/Fe	6-13	15-22	12-20	37-38	15-16	68-127

†Averages of two replicate determinations. Those values not followed by a similar letter are significantly different at the P = .95 level. Tissue from NK-treated subsoil insufficient in amount for total-N

Table 3. Total crop, green pod production, soil pH, and macronutrient herbage concentrations† of 'Williams' soybeans grown on selected overburden materials from the Darmstadt site with and without lime and phosphorus.

Overburden Treatments	Soil pH	Total Crop	Green pod Wt.	Green pod No.	Herbage Macronutrients P	Mg	Ca	K
		-------g------			--------------%--------------			
Control								
Darmstadt Subsoil (B_2)	5.2 a	2.7 a	0.8 a	6.8 ab	.04 a	.26 a	0.76 a	2.18 a
Subsoil:Peorian silt (30 B_2:70 B_3)	6.3 b	4.1 b	1.3 b-d	6.2 a	.10 c	.46 b-d	1.06 cd	1.78 ab
Subsoil:Roxana silt (30 B_2:70 IIB_3)	6.4 bc	4.0 b	1.2 a-c	8.0 ab	.08 bc	.47 b-d	1.04 c-e	1.34 bc
Peorian silt (B_3-stratum)	8.2 h	3.9 ab	1.1 ab	7.8 ab	.09 bc	.43 bc	1.03 bc	1.91 ab
Roxana silt (IIB_3-stratum)	8.1 h	5.4 cd	1.4 b-d	10.8 c	.10 c	.58 d	1.08 cd	1.66 ab
High Wall Mix‡	6.5 c	4.0 b	1.2 a-c	6.0 a	.10 c	.44 bc	1.06 cd	1.38 bc
Lime, Phosphorus§, and Potassium								
Darmstadt (Subsoil (B_2)	6.9 d	4.0 ab	1.2 a-d	6.2 a	.06 ab	.40 b	0.93 b	1.79 ab
Subsoil:Peorian silt (30 B_2:70 B_3)	6.9 d	4.1 b	1.1 ab	6.6 a	.08 bc	.49 bc	1.09 cd	2.13 a
Subsoil:Roxana silt (30 B_2:70 IIB_3)	7.2 e	5.8 d	1.6 cd	11.0 c	.10 c	.58 d	1.12 cd	1.69 ab
Peorian silt (B_3-stratum)	7.9 g	4.0 b	1.1 ab	7.2 ab	.08 c	.41 b	1.05 b-d	1.33 bc
Roxana silt (IIB_3-stratum)	7.7 f	4.5 bc	1.1 ab	8.0 ab	.19 d	.71 e	1.16 d	0.96 c
High Wall Mix‡	6.5 c	5.0 b-d	1.7 d	8.8 bc	.06 ab	.41 b	1.07 cd	0.82 c

†Values are averages of four replicate determinations. Values of the same parameter not followed by a similar range of letters are significantly different at the P = .95 level.

‡"High wall mixture" contains prominant ratios of subsurface (non-topsoil) coal overburden strata to a depth of 4.0 m; i.e. 20, 21, 38, and 21% B_2, B_3, IIB_3, and $IIIB_2$ strata, respectively.

§Lime was not applied to the "high wall" or silt treatments. Potassium was applied at a rate of 51 ppm, 45 days after planting.

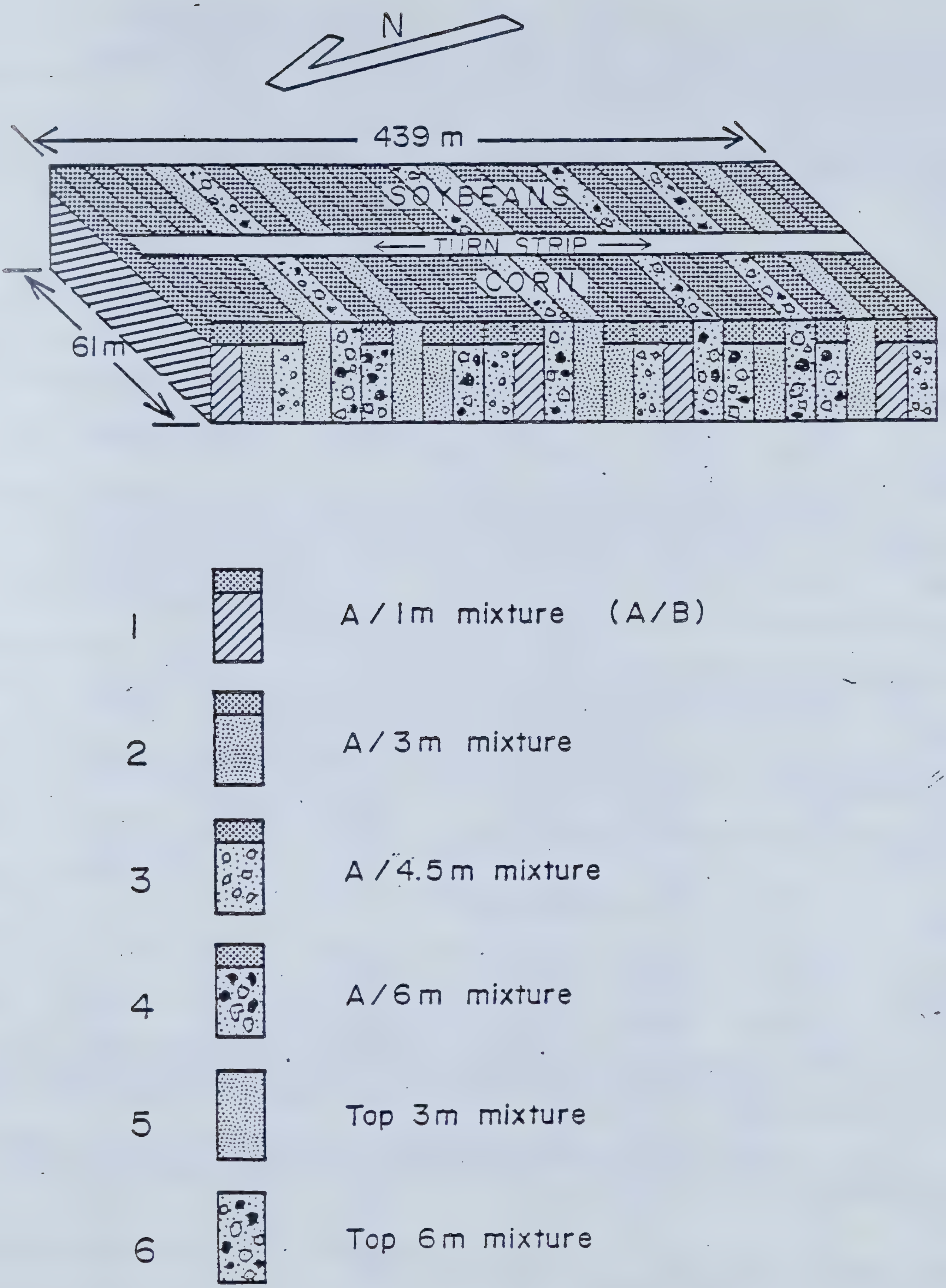

Figure 1. Experimental Plan for the Captain Mixture trial at Captain Mine in Perry County, Illinois.

Greenhouse Experiments

Greenhouse experiments (Dancer 1982a,b,; Dancer and Jansen 1981) have reiterated the view that topsoil is the most suitable overburden media for row crop production, and have illustrated the infertile and potentially toxic nature of the very strongly acid (pH 4.5 - 5.5) "clay-pan" subsoils of the southern Illinois coal field. An interesting synergistic response was observed on forages grown on mixtures of subsoil and the less acid, but leached loess found immediately below the subsoil (Table 1). The elemental composition of field corn (Zea mays L., Table 2) and soybean (Glycine max L., Table 3) shows that subsoil (B_2-horizon) supplies more potassium (K), while the underlying loess (B_3 and IIB strata) provided more phosphorus (P) for plant growth. A mixture of subsoil and underlying loess is therefore beneficial because it provides greater amounts of both P and K than either the subsoil or leached loess alone. Forage test crops were more responsive to subsoil-loess blending (Table 1) than field corn or soybeans, because the forages are more tolerant of the elevated and potentially toxic Al and Mn levels indigenous to the most strongly acid clay pan (pH 4.5) Weir soil (Dancer 1982a,b).

A greenhouse experiment using soybeans and the less acid Mollisol subsoil (pH 6.2), underlying calcareous loess (pH 8.0) and glacial till (pH 7.5) strata from Knox County (McSweeney et al. 1981), indicated that subsoil blending with underlying strata is less beneficial in the western Illinois coal field. In more recent trials, tall fescue (Festuca arundinacea Schreb.) was unresponsive, and alfalfa (Medicago sativa L.) showed a negative response when a Sable subsoil from Knox County was mixed with underlying calcareous loess (Table 4).

Table 4. Relative dry weight yields* of tall fescue and alfalfa grown on Sable subsoil amended with increasing amounts of calcareous loess from Knox County.

Treatment B_2/C_1 Ratio	100/0	75/25	50/50	25/75	0/100
Tall fescue	42a	38a	32a	31a	37a
Alfalfa	84a	97a	89a	60 b	18 c

*Yields reported as percentage of those observed on topsoil. These values for the same crop followed by a different letter are significantly different at the P = .95% level.

Field corn was most responsive to the blending of these subsoil and loess materials as shown in Table 5.

Table 5. Height[+] of field corn grown on Sable subsoil and calcareous loess strata from Knox County, and on a mixture containing equal amounts (by weight) of these materials, in a factorial experiment with phosphorus and potassium.

Treatment	Subsoil	Mixture	Loess
Control	63 bc	86 e	56 ab
K	71 cd	81 e	54 a
P	68 c	69 c	70 cd
PK	78 de	85 e	64 c

[+]Heights were measured 41 days after planting and are expressed as a percentage of the average height of corn grown simultaneous on fully amended (NPK) topsoil. Those values not followed by a similar letter are significantly different at the P = 95% level. All treatments received 150 ppm N as ammonium nitrate. Phosphorus and potassium were supplied at a rate of 150 and 189 ppm, respectively.

These results suggest that the Sable subsoil contains higher amounts of P in a form available for plants, than the calcareous loess; and the addition of fertilizer-P eliminated any advantage of mixing these materials.

Field Trials

The positive response of test crops to blending of "clay-pan" subsoil and loess strata in the greenhouse led to the establishment of a special field experiment in the southern Illinois coal field, at the Captain Mine near Percy, Illinois. An experimental plan is shown in Fig. 1. Several lifts, the first, third, and sixth-meters of overburden below the topsoil were selected using Arch Mineral Corporation's "mini" bucket-wheel excavator and "shuttle-belt" system (Chironis 1981) to establish "rooting-media" treatments consisting largely of (1) subsoil, (2) subsoil and leached loess, with treatments, (3) and (4) having different amounts of glacial till along with the subsoil and loess. Topsoil (9 inches) was then replaced over these subsurface treatments, with the exception of treatments (5) and (6) where topsoil was not segregated, but mixed in with the subsurface loess and till strata. This site received a fertilizer application of 180, 100, and 200 lbs/acre N, P_2O_5, and K_2O, respectively, before corn was planted. The resulting corn grain yields on the 3, 4.5, and 6-meter lifts were highly correlated with the K concentrations in the ear-leaf at early tassel (Fig. 2). Three out of the four composite (10-leaves) tissue samples taken from the subsoil (1-meter) treatment had normal K concentrations; while half of the leaf samples from the 3- and 4.5-meter (subsoil-loess)

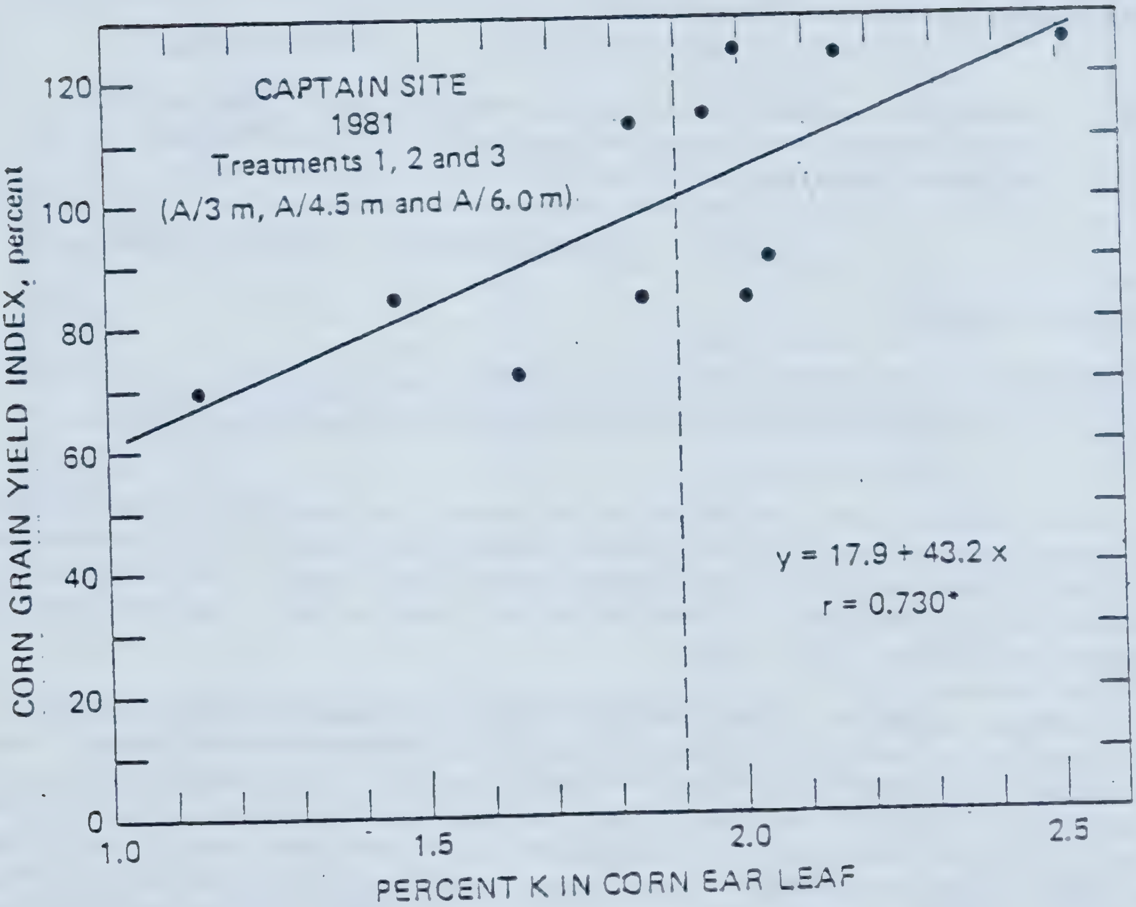

Figure 2. Corn grain yields and their relation to the potassium concentration of ear-leaves at early tassel in the first year of reclamation at the Captain Mixture experiment. Grain yields are expressed as a function of those yields observed on nearby undisturbed land. The lower yields on the undisturbed land were associated with poor weed control.

treatments contained low K concentrations ($<$ 1.9%) indicating a deficient supply of potassium. These first-year observations support the early conclusion from greenhouse experiments (Dancer 1982a,b) that the subsoil in southern Illinois is a important source of K. The amelioration of these strongly acid clay-pan subsoils with these underlying loess strata in southern Illinois appears to decrease the amount of K available for crop production; and higher rates of fertilizer-K will be required, at least initially, to provide adequate levels for row-crop production. Table 6 shows that corn-leaf tissue samples from the 3-meter treatment which theoretically contains the most leached loess, contain significantly higher concentrations of phosphorus.

Table 6. Phosphorus concentrations in corn-ear leaves sampled at early tassel from selected treatments on the "Captain Mixture" experiment in Perry County.

	Subsoil	Subsoil-Loess	Subsoil, Loess, Till	
Treatment Numbers	(1)	(2)	(3)	(4)
% leaf-P	0.23a	0.30b	0.26a	0.26a

These results are consistent with these from greenhouse experiments and soil test observations (Dancer 1982a; Dancer and Jansen 1981; Snarski et al. 1981) which indicate that the leached loess (B_3C_1 strata) in southern Illinois contains higher amounts of P available for plant growth than the associated clay-pan or glacial till strata.

Nitrogen appeared to be the most important macronutrient limiting corn grain yields on the 3- and 6-meter mixture treatments where topsoil was not segregated but mixed with deeper strata (Fig. 3). It is estimated that the topsoil in southern Illinois, when replaced, may supply from 40 to 70 lbs. of N per acre. Nitrogen deficiency is considered less important than P and K deficiency because fertilizer-N additions of 150 to 200 lbs/acre are required for corn production, and soybeans generally fix and acquire adequate amounts symbiotically with *Rhizobium japonicum*.

Nutritional Imbalance, a Syndrome on Newly Reclaimed Land

Chemical analyses of leaves sampled from field corn and soybeans growing on newly reclaimed land in Illinois show that row-crops contain unusually high amounts of metals, e.g. iron, aluminum, and manganese; with low, often deficient concentrations of potassium and sometimes phosphorus. This syndrome was most clearly expressed on land reclaimed without topsoil where row-crops were grown directly on graded overburden from dragline and large bucket-wheel excavation operations in southern Illinois (Table 7).

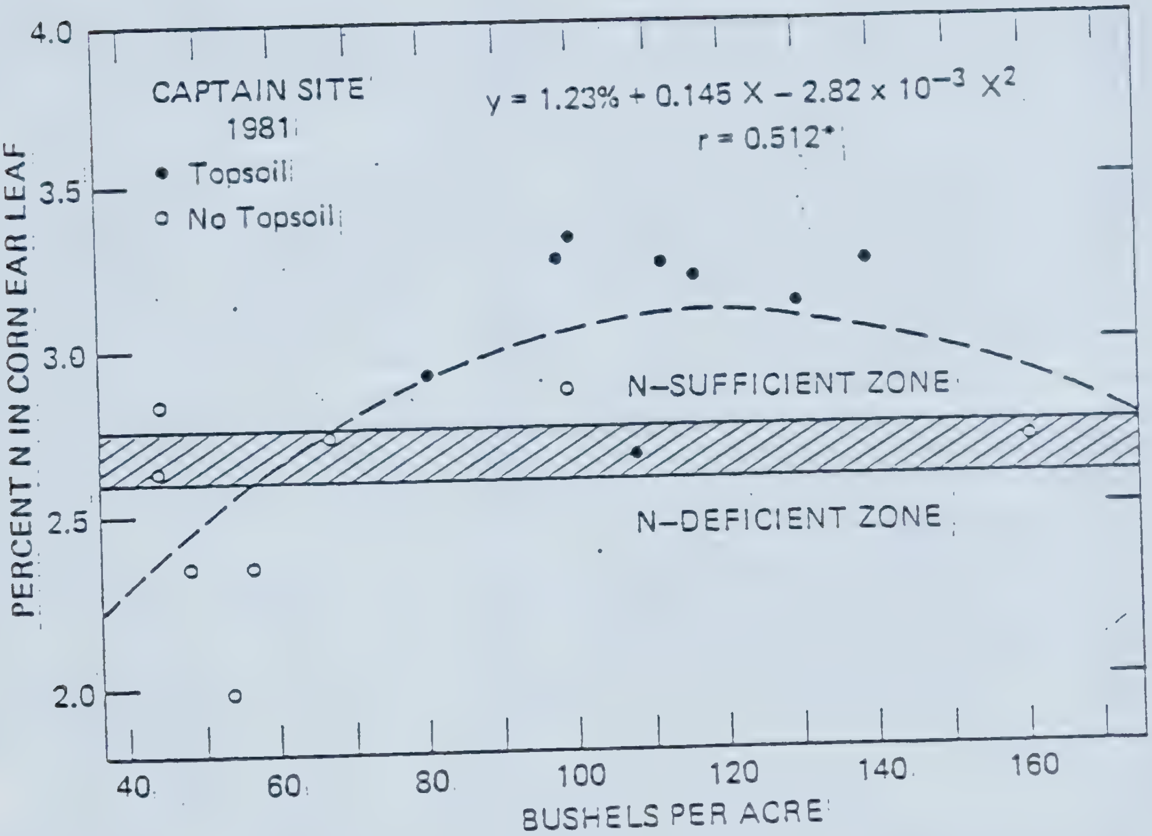

Figure 3. Corn grain yields and their relation to the nitrogen content of ear-leaves at early tassel in the first year of reclamation at the Captain Mixture experiment.

Table 7. Elemental composition of corn and soybean leaves sampled during the first three years after the reclamation of land disturbed by surface coal mining in southwestern and west-central Illinois.

Elemental Composition	I. Field Corn (*Zea mays* L.) ear-leaves sampled at early tassel in A. Southwestern Illinois on: 1. Dragline	2. Bucket-wheel	3. Hauled† overburden	B. West-central Illinois on: 4. Dragline	5. Bucket-wheel overburden
(percent)	(pH 3.4-7.3)	(pH 7.1-7.8)	(pH 5.1-6.7)	(pH 7.2-7.8)	(pH 7.5-7.8)
Phosphorus	0.26-0.32	0.24-0.36	0.24-0.30	0.11-0.32	0.22-0.22
Potassium	1.81-1.82	0.62-0.84	1.79-2.67	2.09-2.63	1.68-1.75
Calcium	0.38-0.51	0.60-0.90	0.48-0.59	0.46-0.66	0.56-0.60
Magnesium	0.22-0.39	0.26-0.40	0.28-0.38	0.15-0.47	0.31-0.42
(ppm)					
Aluminum	44-85	114-167	< 10	7-193	< 10
Magnesium	236-278	168-232	61-131	49-96	47-52
Iron	128-131	124-166	110-148	13-214	41-61
Zinc	37-40	25-38	46-94	27-71	24-32
Copper	9-13	15-20	8-13	5-12	10-12
Boron	14-20	12-56	18-20	11-21	11-40
II. Soybean, (*Glycine max* L.) fully-expanded leaves sampled at mid-flower.					
(percent)					
Phosphorus	0.29-0.30	0.16-0.40	-	0.19-0.26	0.22-0.32
Potassium	1.22-1.83	0.44-2.36	-	2.08-2.54	1.43-1.82
Calcium	0.92-1.08	0.92-2.19	-	1.12-1.17	1.15-1.19
Magnesium	0.49-0.88	0.45-0.88	-	0.31-0.41	0.52-0.68
(ppm)					
Aluminum	321-525	137-650	-	211-261	87-131
Magnesium	217-304	62-304	-	81-91	66-94
Iron	289-396	118-492	-	226-278	139-162
Zinc	29-49	10-61	-	32-56	39-75
Copper	12-16	5-18	-	9-11	9-12
Boron	40-53	38-102	-	46-76	40-85

†Overburden hauled by scrapers in a shovel operation.

Soybeans consistently contained higher metal concentrations than corn, presumably due to the greater ability of soybeans to excrete acids and reductants from their roots to alter the growing media (Dancer 1982a).

Minespoils produced by dragline and bucket-wheel operations tend to contain rock fragments from the older Pennsylvanian strata, especially shale fragments. The high metal uptake by plants on newly reclaimed land appears to be associated with a rapid weathering of these rock fragments, along with those present in the loess and glacial till sediments. The dragline operation at site 1 (Table 7) is located in south-central Illinois where the unusual Opdyke coal member of the Mattoon formation is being mined. This site is unusual because the Opdyke coal is overlain by shale and a pyritic limestone (Nance and Treworgy 1981), and there is insufficient lime to neutralize the acid produced by pyrite oxidation in the northern fourth of the research site. As a result the pH of individual plots† varies from 3.5 in the north to 7.5 in the south where the spoil appears to contain enough free lime to neutralize any acid that has formed. This accelerated weathering by pyrite oxidation was accompanied by a reduction in soybean grain yield in 1979 as the pH decreased from 6.7 to 4.6 (Fig. 4), presumably because of aluminum toxicity. The replacement of 8 inches of topsoil ameliorated the overburden acidification and toxicity at this site; and topsoil replacement has consistently lowered the metal concentrations in crop leaves at all sites (unpublished data). Soybean grain yields were highest at site 1 when the overburden below the topsoil had a pH of 6.8 (Fig. 4), which suggests that some acidification is beneficial. Soil tests taken at this site show that an increase in exchangeable-K accompanied acidification (Dancer et al. 1982). The weathering of feldspar and micaceous minerals in the sand fractions of the Pleistocene loess and tills (Frye et al. 1960, 1962) is the most probable source of this K since the Pennsylvanian strata generally contain few weatherable minerals that contain K, with the exception of some of the sandstone members (Potter and Glass 1958).

Unpublished evidence from sites 2, 4, and 5 (Table 7) indicate that exchangeable-K build-up from fertilizer applications occur more slowly in minespoil than topsoil; and may actually decrease initially. This decrease in available-K appears transient because exchangeable-K build-up rates were similar in minespoil and topsoil in the third and fourth year at site 2, after a reduction had been observed in the bucket-wheel overburden in the first two years. This initial decrease in exchangeable-K may be caused by mineral "K-fixation" because the newly exposed Pleistocene loess and glacial till sediments contain higher amounts of expandable clay minerals than the modern soils in Illinois (Snarski et al. 1981; Frye et al. 1960, 1961). Shale weathering may also contribute because shale disaggregation or slaking

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†Details about the plot size, experimental plan, management and cropping are presented elsewhere (Jansen and Dancer 1981).

is most rapid when they contain high levels of expandable clay minerals (Odom 1963). Also the high levels of free lime in these minespoils tends to increase the energy required for K ions to replace Ca and Mg ions on the soil exchange (Woodruff 1955) making K less available for plant uptake.

Site 2 appears to be unusual chemically because plants initially contained very high amounts of metals as well as deficient concentrations of potassium (Table 7), even when the site is neutral or slightly alkaline (pH 7.1-8.0).

Extraction of the bucket-wheel overburden at site 2 with 0.1 N H_3PO_4 revealed that it contained unusually high amounts of "available-Mn" (86-124 lbs./acre). Alkaline and calcareous soils usually contain less than 70 lbs./acre, and are sometime deficient in Mn for crop growth (Hammes and Berger 1960). Linear correlation analyses showed that soybean grain yields (1978-1981) were highly and negatively correlated with their Mn leaf levels at mid-flower ($r = -.731^{**}$). This suggests that Mn toxicity was an important mechanism for limiting grain yields initially at this site. The toxicity was only temporary, and Mn leaf levels dropped drastically by the third year (see low values in Table 7); and normal levels were observed in the fourth year (unpublished observations). Similar observations were made by Wallace et al. (1976, 1980) when he tested coal and pyrite as sources of iron and sulphur in the greenhouse. Powdered coal depressed K uptake by snap beans (*Phaseolus vulgaris* L.), and pyrite addition resulted in a yield reduction caused by Mn toxicity, while soil pH remained neutral.

Corn grain yields were also low initially at site 2, and corn appeared to be deficient in potassium, as well as having high metal concentrations (Table 7). Potassium deficiency has been the most common symptom of the "nutrient imbalance syndrome" on newly reclaimed land. Corn and soybean plants with the "tip-burn" and leaf-blade margin necrosis characteristic of potassium deficiency have been observed at most sites. Water and heat stress during periods of drought appeared to intensify this problem in some years.

Summary

Evidence from plant leaf analyses and soil tests indicates that there is commonly a nutritional imbalance syndrome in field corn and soybeans grown on newly reclaimed land. The syndrome is characterized by low, often deficient, concentrations of potassium in plant leaves and by high metal concentrations that occasionally become toxic. Phosphorus deficiency symptoms have also been observed, but are ephemeral, and probably induced temporarily by high levels of soluble aluminum. The syndrome is transient, and the potential for potassium deficiency has been successfully eliminated in three or four years with good fertilizer management.

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COAL MINE RECLAMATION
IN CAPE BRETON

A PAPER PRESENTED TO
THE CANADIAN LAND RECLAMATION ASSOCIATION
1982 ANNUAL MEETING IN SYDNEY, NOVA SCOTIA

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COAL MINE RECLAMATION IN CAPE BRETON

BY

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ABSTRACT

In the summer of 1977 the Cape Breton Development Corporation embarked on a major cleanup and reclamation program of abandoned mine sites in the Sydney coal field. The Nova Scotia Department of the Environment was approached by Devco for assistance and promptly pledged full cooperation in achieving the objectives of the cleanup effort.

Three sites in New Waterford were selected by the Department for restoration. The abandoned mine sites were contoured, limed, fertilized and hydroseeded. Surface debris was removed from the sites and what was formerly an ugly scar in the centre of New Waterford is now an aesthetically pleasing green belt area. Approximately 40 acres were involved at the three New Waterford sites.

Another project successfully completed involved the restoration of No. 6 Colliery at Donkin. The Donkin reclamation required ditching to improve drainage in the area and demolition of old concrete works, including the mine portal, air shaft, boiler house foundations and other bankhead structures. The work was carried out in cooperation with and complementary to adjacent development and community projects underway at the time.

The purpose of these efforts was to provide leadership in demonstrating that abandoned mine sites can be restored to enhance the aesthetics and potential of the areas in which the mines previously operated.

INTRODUCTION:

Canada's economic and social well being depends to a large extent upon the extraction of minerals and the production of fossil fuels. The energy contained in fossil fuels is generally found underfoot in the form of coal, oil or natural gas. The extraction of energy and in particular the mining of coal traditionally has resulted in ugly scars upon earth's tender skin.

But times have changed! Canadians have become increasingly militant toward those who scar the land and at the same time attempt to avoid public accountability. Mining companies in North America today are well aware of public pressure which demands the application of technology to heal surface disturbance scars. In a word, there is a recognition that reclamation is essential if man is to repay his debt to the land which sustains life on earth. Man has belatedly recognized the necessity to apply the healing arts to earth's damaged face.

Definitions:

Reclamation - The Managing Director of the Coal Association of Canada in a keynote address at the Coal Industry Reclamation Symposium in Banff in 1977 defined the terms "Reclamation" and "Rehabilitation".

Reclamation - "Those remedial measures necessary to alleviate or eliminate conditions arising from surface mining".

Rehabilitation - "is the next stage, comprising land development for specialized and more productive uses contributing to the economic potential or social improvement of an area".

Alberta regulations, introduced since 1973, regard reclamation as a process to restore land after a surface disturbance to a "level of productivity equal to or greater than that which existed prior to development".

STRIP MINING

Strip mining is a type of surface mining, commonly associated with coal in which the overburden is stripped off to gain access to the coal seams.

In the Little Pond area of Cape Breton you will find the remains of Number 7 Colliery on the Lloyd's Cove Seam. A strip mine was opened at this site in 1946 and abandoned in 1950. The Nova Scotia Steel and Coal Company Limited discontinued the operation when the depth of overburden on the coal seam reached an average of 60 feet. Mining operations continued underground until 1955 when the operation was terminated.

Unfortunately, nothing was done to reclaim the scarred landscape left behind by the strip mining operation when it was abandoned. The spoil piles and water filled cuts still stand as mute testimony to the indifference of earlier times.

Alder Point

In 1973 the Cape Breton Development Corporation faced a shortage of coal brought on by the world energy crisis. No. 12 colliery at New Waterford had been closed, the new Lingan mine had not yet achieved full production and No. 26 Colliery at Glace Bay was experiencing problems.

Devco, as it was known in those days, decided as a short term solution to the coal shortage to begin surface mining operations. Thus strip mining again returned to the coal industry in Cape Breton.

Devco's plans called for the development of a strip mine on a 45 acre site under the guidance and cooperation of the Provincial Department of the Environment. Devco and the Nova Scotia Department of the Environment worked closely to develop plans for reclamation of the site.

The experiment at Alder Point was an outstanding success and stands as a visible reminder that the indifference of earlier years and the ugly memories conjured up by that indifference can be overcome.

The site selected by Devco for the initial project at Alder Point is about 20 miles northwest of Sydney. Charged with the overall direction of the project was Roy MacLean, Director of Mines Planning for Devco. Chief engineer on the job was Barclay Cunningham, while Bill Coulter represented the Nova Scotia Department of the Environment.

Coal on the site was in two seams (Upper and Lower Bonar Seams). The top seam runs three to three and one half feet thick and the lower is four to four and one half feet thick. The two seams are separated by approximately three feet of rock. The seams cropped about 700 feet from the Atlantic Ocean on a 10% grade. The stripping area ranged from 30 to 50 feet above sea level and was fairly flat with a dense growth of evergreen trees.

Extensive bootlegging had been carried out at each end of the proposed stripping area. No lakes or streams were located on the property to create water pollution problems. It was decided to leave a stand of trees along the coast line to act as a windbreak to prevent soil and newly planted vegetation from being blown away during reclamation.

Appended to this report is a detailed account of the reclamation activities of this project.

New Waterford

In the summer of 1977 the Cape Breton Development Corporation embarked on a major cleanup and reclamation program of abandoned mine sites in the Sydney coal field. The Nova Scotia Department of the Environment was approached by Devco for assistance and promptly pledged full cooperation in achieving the objectives of the cleanup program.

Three sites in New Waterford were selected for restoration. The abandoned mine sites were contoured, limed, fertilized and hydroseeded. Surface debris was removed from the sites and what was formerly an ugly scar in the centre of New Waterford is now a pleasant looking green belt area. The three sites selected for reclamation were as follows:

No. 12 Colliery - 30 acres
No. 14 Colliery - 5 acres
No. 15 Colliery - 5 acres

Considerable preparatory cleanup had been completed by Devco when the Hydroseeders arrived early in September. The equipment, application materials and personnel were made available to NSDOE by the Nova Scotia Department of Transportation. A mixture of grass seed, fertilizer and limestone was applied to the three sites over a period of seven days.

Three Hydroseeders and 2 supply trucks moved on site September 12, 1977. The following day, a first pass was made with the hydroseeders using a mixture of:

2 tons Agricultural Limestone per acre
1 Bushel Oats per acre
1000 Gallons of Water per acre

On September 14th a second pass was made using the regular Highway seeding formula of:

1 ton Agricultural Limestone per acre
325 lbs. Fertilizer 10-29-8 per acre
50 lbs. Grass Seeds per acre

This premix is used in 1000 gallons of water per acre of treated soil.

Grass Mixture - The grass consists of a mixture of the following:

40% Creeping Red Fescue
15% Timothy
10% Kentucky Blue
10% Alsike Clover
15% Tall Fescue
5% Annual Rye
5% Red Top

At the recommendation of Dick Morton, NSDOA a follow-up application of 6-12-12 at the rate of 500 lbs per acre and nitrogen (ammonium nitrate) at the rate of 100 pounds per acre was carried out in June 1978. Since the DOT hydroseeders were not available in the Spring of 1978, area farmers were approached on a selective tendering basis from a list supplied by the Department of Agriculture. This approach had been recommended to us by Mr. Gordon Boutilier, Horticultural Manager of Devco who was involved in all phases of the reclamation and proved to be an invaluable resource person.

In addition to the three sites previously mentioned a small parcel of land approximately one acre in size at the Low Point Air Shaft was also hydroseeded.

In clearing the three colliery sites a considerable quantity of buried steel cable and tramp iron was encountered. Cutting torches had to be employed to assist in the removal of the cable and a general surface debris removal carried out.

Since the project was commissioned in September, there was an extremely tight schedule to seed for fall germination. The DOT crew was under the direction of Mr. Percy Ellis, Superintendent from the Truro office. On September 19, 1977 seeding operations were completed.

The project was recognized at the time as a good example of successful cooperative efforts by three Provincial Government Departments and the Cape Breton Development Corporation. Essentially, the job was completed on time and in this case under budget.

Adjusting the acreage for surface structures, a rail repair shop and drainage ditches, a total of 25.5 acres were hydroseeded at the three New Waterford sites.

The total cost of reclamation - $500.00 per acre.

Slides 1-15 illustrate the work undertaken at New Waterford.

<u>Donkin</u>

Another project successfully completed involved the restoration of No. 6 Colliery at Donkin. The Donkin site required ditching to improve drainage in the area, and demolition of old concrete works, including the mine portal, air shaft, boiler house foundations and other bankhead structures. The work was carried out in cooperation with and complementary to adjacent development and community projects underway at the time.

On October 25, 1977, the first stages of land reclamation on a 15 acre site at Donkin began. Earth moving equipment was contracted to contour the land and provide drainage so seeding for the growth of turf grasses could be carried out the following spring. Twelve days were required to attain the desired contours and drainage pattern. A soil sampling program was commenced to provide nutrient information for the seeding operation in the spring of 1978.

When No. 6 Colliery closed in 1933 it left behind a desolate array of air shafts, concrete works, tailing piles and the mine portal as mute testimony to earlier indifference. To reclaim the land it was necessary to level the foundations and tailing piles, collapse and backfill the portal so that desired contours could be obtained.

Heavy equipment employed on the job consisted of:

a) D-8 Bulldozer
b) 50 Komatsu
c) Drott Crain Backhoe
d) Compressor, Drills and Dynamite

The concrete foundations resisted the efforts of heavy equipment and thus it was necessary to dynamite the structures and bury the fragmented concrete. One interesting anecdote involved the dynamiting and removal of works located about 100 feet from the ancestral home of the President of Devco. Blasting mats were employed and every precaution taken to ensure the safety of nearby residents.

The contouring stage of reclamation ran very smoothly. The twelve working days were generally sunny with little precipitation. The excellent weather provided good drying and working conditions.

One problem experienced during this stage was the rupture of the Town's main water line during the excavation of a drainage ditch. Plans of the area did not show the water line and its discovery was unexpected to say the least. However, the Cape Breton County Works Department arrived soon after and the line was quickly resotred to service.

The reclamation site is situated in the heart of the Town as can be seen from the accompanying slides. Slides 16-30. Aerial photographs of the Donkin site before reclamation began are appended to this report.

The reclaimed site greatly improves the aesthetics of the area, providing additional land for public use complementary to existing uses.

<u>Grass Seed Mixture</u>

400 lbs. Creeping Red Fescue
150 lbs. Timothy
100 lbs. Kentucky Blue
100 lbs. Alsike Clover
150 lbs. Tall Fescue
50 lbs. Annual Rye
50 lbs. Red Top

Hydroseeding Formula:

The hydroseeding formula employed at Donkin consisted of the following:

90,000 lbs. Agricultural Limestone (bulk)
4,500 lbs. 12-24-24 Fertilizer (bags)
1,000 lbs. Grass Seed Mixture (bags)

Application Rates:

The application rates were as follows:

Agricultural Limestone	- 3 tons/acre
Fertilizer 12-24-24	- 300 lbs./acre
Grass Seed Mix	- 50 lbs./acre

Total Cost including demolition - $1,540./acre

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ACKNOWLEDGEMENTS:

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1. Gordon T. Boutilier, Horticulture Manager, The Cape Breton Development Corporation, Sydney, Nova Scotia.

2. W. A. Coulter, Environmental Engineer, Nova Scotia Department of the Environment, Halifax, Nova Scotia.

3. Barclay J. Cunningham, Project Manager, Cape Breton Development Corporation, Sydney, Nova Scotia.

4. Percy Ellis, Nova Scotia Department of Transportation, Truro, Nova Scotia.

5. Steve MacNeil, Cape Breton Development Corporation, Sydney, Nova Scotia.

6. Harvey MacDonald, Nova Scotia Department of Agriculture, Sydney, Nova Scotia.

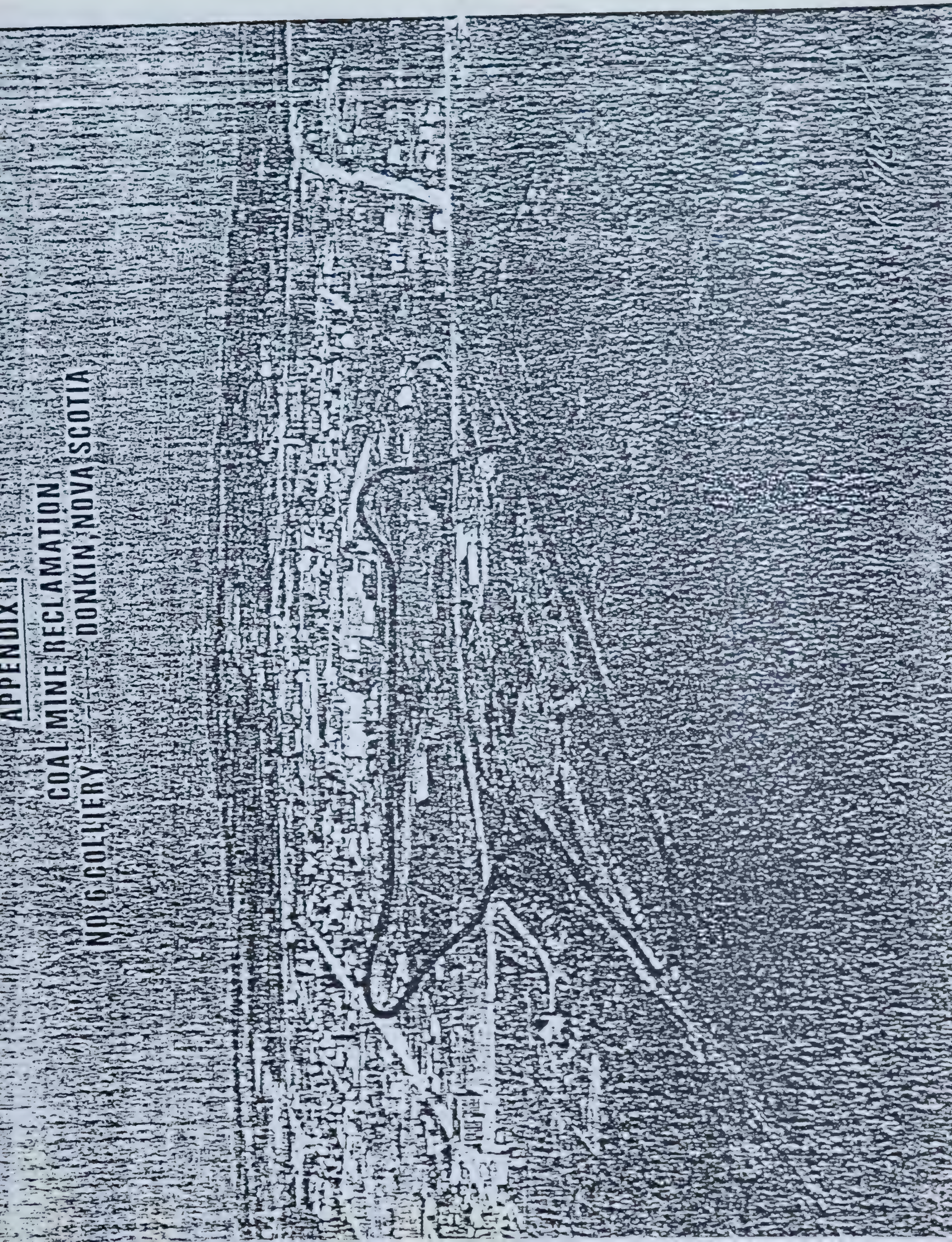
7. John O'Brien, Cape Breton Development Corporation, New Waterford, Nova Scotia.

8. Ian Swan, Nova Scotia Department of Agriculture, Truro, Nova Scotia.

9. C. J. Smith, Executive Engineer, Nova Scotia Department of Transportation, Halifax, Nova Scotia.

10. Don R. Sutherland, Nova Scotia Department of Transportation, Halifax, Nova Scotia.

11. Richard S. Morton, Nova Scotia Department of Agriculture, Truro, Nova Scotia.


APPENDIX I
COAL MINE RECLAMATION
NO.6 COLLIERY DONKIN, NOVA SCOTIA


ONKIN RECLAMATION
LOSE UP
APPENDIX III

APPENDIX III

SOIL TEST REPORT

Nova Scotia Department of Agriculture and Marketing
Soils and Crops Branch, Truro, N.S.

DONKIN RECLAMATION SITE

Laboratory No.: 75222/1-8
Date Received: 24/11/77
Date Reported: 14/12/77
Lab Supervisor:

N.S. Dept. of the Environment
P.O. Box 714, Sydney, C.B. Co., N.S.

Copy to: Mr. G. T. Boutilier, P.O. Box 1330
Sydney, Cape Breton Co., Nova Scotia

NOTE: SOIL TEST RATINGS and REQUIRED NUTRIENT APPLICATIONS are for crops specified.
A CHANGE OF CROP will require new SOIL TEST RATINGS and may require different NUTRIENT APPLICATIONS.

Sample No.	Field No.	Crop to be Grown	Soil Test Values – Soil Test Ratings for Crops specified													Required Applications		
			O.M. %	L.R. T/A	pH	Nitrogen lb/A	Nitrogen rating	Phosphate lb/A	Phosphate rating	Potash lb/A	Potash rating	Calcium lb/A	Calcium Rating	Magnesium lb/A	Magnesium rating	Nitrogen lb/A	Phosphate lb/A	Potash lb/A
1	1	Establish Coarse Turf	25.7	6.0	4.7			200	H–	145	M	870	L	72	M–	35	20	30
2	2	Establish Coarse Turf	10.1	12.5+	4.1			105	M–	90	L+	400	L–	38	L+	35	40	50
3	3	Establish Coarse Turf	82.5	4.5	3.9			50	L–	40	L–	190	L–	9	L–	35	75	75
4	4	Establish Coarse Turf	14.0	--	7.1			310	H	256	H	2880	M+	360	H–	35	0	0
5	5	Establish Coarse Turf	8.5	4.0	5.4			110	M–	90	L+	1220	L+	150	M	35	40	50
6	6	Establish Coarse Turf	17.4	7.0	4.7			80	L+	95	L+	750	L–	92	M–	35	50	50
7	7	Establish Coarse Turf	26.0	1.0	6.2			90	L+	85	L+	1960	M	88	M–	35	50	50
8	8	Establish Coarse Turf	7.4	7.5	4.9			80	L+	110	M–	280	L–	113	M	35	50	40

NOTE: O.M. – Organic Matter; L.R. – Lime Requirement; Nitrogen – lb/A, N ; Phosphate – lb/A, P_2O_5; Potash – lb/A, K_2O; Calcium – lb/A, Ca. Magnesium – lb/A, Mg.

Suggested Treatments:

To provide sufficient fertility for the establishment of coarse Turf, 200-300 lbs. of 12-24-24 fertilizer per acre should be applied.

Limestone should be applied at 3-4 tons per acre.

Area #4 does not require these applications.

G. Ian Swan

If further assistance is required Contact Your County or District Agricultural Office.

APPENDIX IV

environs

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Strip Mining Pilot Project Proving Reclamation Viable

Simply mention strip mining among a group of environmentalists and a chorus of rotest will rise. So ingrained in environmentalists are the images of a raped and avaged earth's surface which strip mining calls to mind that protest is almost utomatic.

These ugly pictures conjured up by the erm "strip mining" do not necessarily ave to hold true. And the Cape Breton Development Corporation (DEVCO) has been in the process over the last two years proving that strip mine site reclamation can be, and is, a viable objective while leaving adequate margin in operations for profits.

Strip mining, quite simply, is a type of surface mining, usually associated with coal, in which overburden on top of coal seams is literally stripped off in order to remove the coal in the seam or seams. Of course, advance planning is needed if the coal is to be removed economically and the area reclaimed once the coal is removed.

Several considerations must be kept in mind: the coal seam or seams should be relatively close to the surface; the seam(s) should be relatively horizontal in respect to the ground surface, and the mining system and stripping area must lend themselves to reclamation.

DEVCO's Coal Division found in late 1973 that coal shortages, in the light of a world energy crisis, had become serious. Number 12 colliery at New Waterford had been closed, the new Lingan mine had suffered delays in start-up, and Number 26 colliery at Glace Bay was undergoing a series of problems.

It was decided, in the light of these facts, and as a short term solution to the coal shortage, to initiate a pilot project, possibly leading to a large-scale, full-time operation, and strip mining was once again introduced to the Cape Breton coal industry.

The provincial Department of the Environment co-operated with DEVCO in developing the plans for the reclamation and monitored the operation. Bill Coulter, staff engineer, Environmental Assess-

(Continued on Page 2)

An overall view of a strip mining site at Point Aconi shows the extent of the operations. Overburden on the left has been pushed back in order to get at the coal seam. It will be used to fill the strip, then top soil spread and seed planted to complete the reclamation.

Old Bootleg Pits Scar Landscape

It's been almost a Cape Breton tradition in coal mining areas since the first settlers arrived to mine the seams of coal that crop at the surface of the ground. The ease of access was perhaps the main factor in the popularity of this activity.

Many the shaft has been sunk on the sly just off an access road on any property that was an obvious spot where a coal seam should be cropping. Popularly known as "bootleg" pits, many of the little independent mines were very productive.

The main fuel used by Cape Bretoners for decades was coal, and it has been only recently that a gradual switchover to oil, electricity and propane gas in some households has reduced the number of backyard coal sheds that once were common.

Selling bootleg coal probably never made anyone rich, but often it helped pay a few bills and certainly kept the price of home heating down.

In some particularly coal-rich areas bootleg pits literally dot the landscape. Government authorities have expressed concern about these pits mainly because of the dangers of cave-ins and the fact that the convenient holes are being used as garbage dumps. Frequent fires occur in these garbage pits through either spontaneous combustion or carelessness and thoughtlessness. Often, the fires burn for days and even weeks, feeding on coal in the pit. Some have been known to smoulder for years.

Bootleg mining operations found during the strip mining operations at Alder Point proved to be more than just simple holes in the ground. In one area a shaft was found that measured approximately 40 feet in

(Continued on page 4)

rty-five acres of reclaimed land which had been mined by stripping is now reclaimed d seeded and will be put into agricultural use in future.

(Continued from Page 2)

d mixture was 60 per cent Timothy, 10 cent Perennial Rye, 10 per cent Alsiki over and 10 per cent Red Clover.

Seeding operations were completed by gust 20. Results proved, for the most rt, to be successful with the mixture king root in all areas. The complete eding operation including labour, uipment rentals, seed and fertilizer cost der $11,000.

It should be noted that costs for clamation were set aside by DEVCO om the sale price of the coal produced, us being built into the overall cost of oduction.

The experiment at Adler Point has been eemed a success by DEVCO and by the rovincial Department of the nvironment.

Following quickly on the completion of e mine at Alder Point, DEVCO decided strip mine and reclaim two more sites, e MacNeil and the Bardswich, at nearby oint Aconi.

While the Alder Point strip mine roduced 129,000 tons of coal, the MacNeil rip mine, which started up in October, 974 produced 148,000 tons from the Hub eam before it closed in October, 1975.

The MacNeil was stripped on a 45-acre ite with much the same surface onditions as Alder Point. The site eclamation began in June, 1975 at the MacNeil and was completed in July, 1975.

The second mine at Point Aconi, the Bardswich, is currently being strip mined over the Harbour Seam. Since its start-up n August, 1975, the mine has produced some 28,000 tons of coal to date and is expected to wind up operations July, 1976. The reclamation on this 35-acre site is expected to begin in August, 1976.

While both DEVCO and the provincial Department of the Environment have been pleased with this pilot project and the further strip mining will be undertaken in the near future. This is due mainly to the fact that present production from the underground coal mining operations is sufficient to meet current demands.

Chlorination Workshop

A workshop in basic gas chlorination will be held in Halifax March 29 to April 2, 1976 for eligible waste and wastewater treatment plant operators. Sponsored by the Nova Scotia Department of the Environment, the workshop will be conducted by personnel of the Ontario Ministry of the Environment.

Details and application forms are available from:

Inspection and Monitoring Division
Nova Scotia Department of the Environment
P.O. Box 2107
Halifax, Nova Scotia
424-8624

ESTABLISHMENT OF RECLAMATION PLOTS AT GENESEE 1981

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ABSTRACT

The Genesee mine site is situated 50 kilometres southwest of the City of Edmonton on the south side of the North Saskatchewan River in Township 50, Ranges 2 and 3, and in Township 51, Range 3, West of the Fifth Meridian.

The primary impacts of the project will be on local agriculture. Seventy percent of the land in the mine is under cultivation. The remaining thirty percent is unbroken. The mining operation will disturb approximately 1,500 hectares of Class 3, or poorer, capability soils over the 30-year project life. It is estimated that mining will disturb an average of 50 hectares each year. Reclamation activities will follow mining operations in a progressive manner . . . so that approximately 500 hectares will be out of agricultural production at any period during mining.

The main objective of the field plots is to provide information on surface soil reconstruction procedures to use during the first five reclamation years (1989 - 1994). Beyond that, it is expected that knowledge gained from the 1989 - 1994 period will contribute to reclamation procedures between reclamation years five and ten (1995 - 2000). Secondary objectives are to provide assurance to local residents and government agencies that successful soil reconstruction and revegetation can be achieved and to document current productivity of Genesee soils.

Finally, the plots may suggest further research projects aiding future reclamation efforts.

The main purpose of this presentation is to describe briefly the objectives of the field plots, their location in the Genesee area, and the design and methods used in their construction during 1981.

GENESEE TEST PLOTS

1. INTRODUCTION

The Genesee Power Project consists of a coal fired thermal generating plant presently being constructed by the city of Edmonton, Edmonton Power at the Genesee project site 50 km southwest of Edmonton in Alberta. (See Figure #1)

Fording Coal Limited of Calgary will act as the operator and manager of the surface mine to supply coal for the power plant's two 400 megawatt capacity generators to be operational by 1986.

The coal mining methods will include truck shovel and dragline extracting an estimated 3,000,000 metric tonnes per annum. Approximately 50 hectares (ha) of land will be mined each year of the 30 year mine plan.

In the Genesee area the topography varies from gently rolling to flat and slopes generally in a north easterly to north westerly direction. Topography elevation ranges from 782 M to 730 M. The mine area lies within the physiographic region known as the Central Alberta Plains, a region characterized by low relief overlain with a thin deposit of glacial drift and recent alluvial sediments. The region is underlain by a succession of essentially terrigenous sandstones and shales and coal beds of late Cretaceous and early Tertiary ages. These have been very slightly deformed by regional tectonic and local glacial processes.

The Genesee area is within the temparate zone with a mean annual precipitation of 44 cm and an average annual temperature of 3°C.

Primary impacts of the project will be on the local agricultural base. Approximately 70% of the mine area is under cultivation with the remaining 30% unbroken, as in pasture and woodlots. The mining operation will disturb approximately 1500 ha of Class 3 or poorer soils over the life of the project.

Reclamation activities will follow mining in a progressive manner so that only 300 to 500 ha will be removed from agricultural production at any given time during mining. Haul roads and other facilities are included.

In 1980-81, Fording Coal Limited and Western Soil conducted a detailed soil and overburden survey within the mining area. This indicated that significant variations exist with respect to chemical and physical properties of surface soils and overburden materials. Taking this into

PROJECT LOCATION MAP

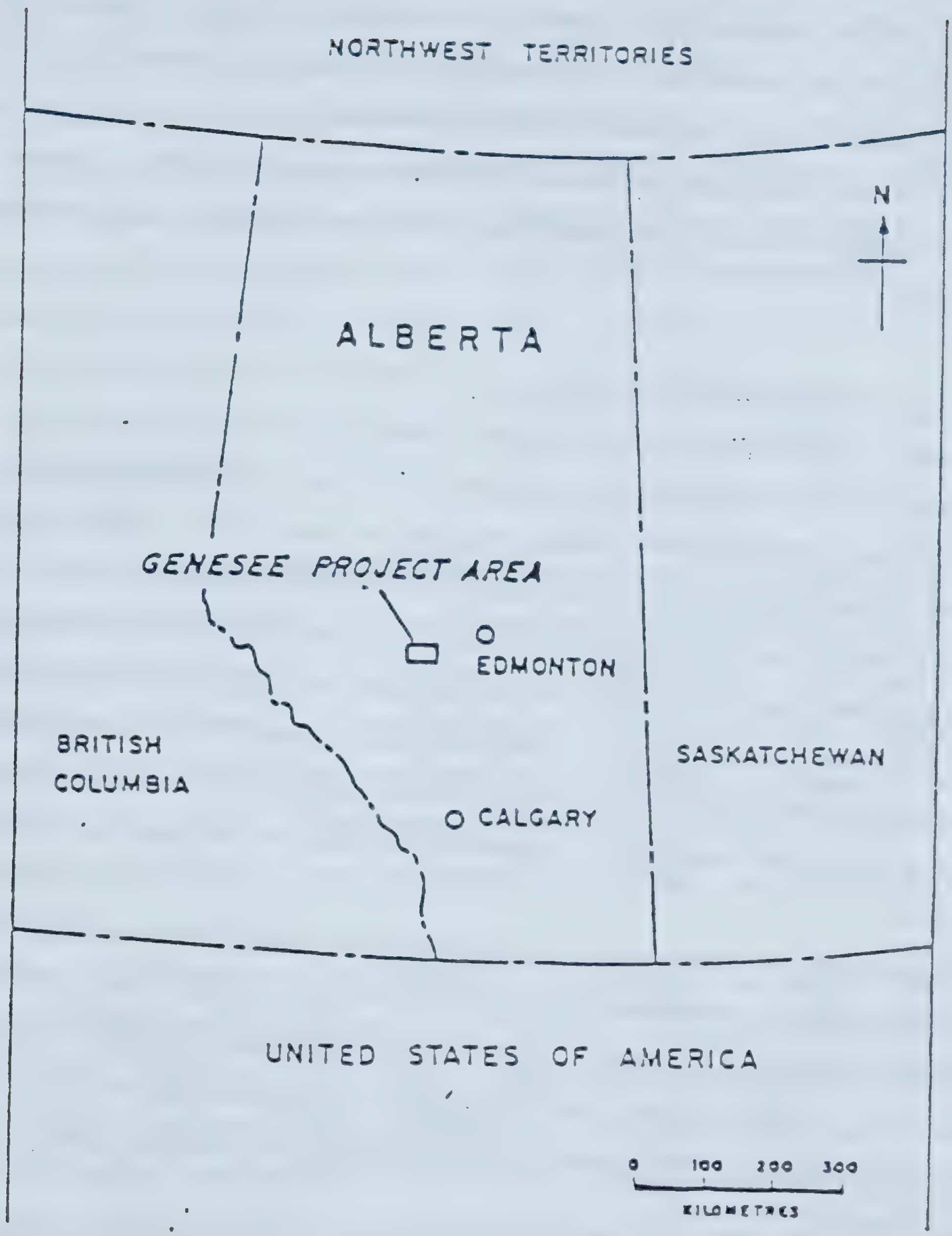


Figure #1

consideration, mine development and reclamation plans were developed during 1981 to provide for coal exposure and removal while ensuring that soil materials were properly salvaged for reclamation use.

Regrading operations are scheduled to commence in 1989 or when sufficient areas are available for full scale field reclamation. Fording Coal Limited and Western Soil established reclamation plots at Genesee during 1981 to provide comparative data on a number of soil reconstruction alternatives. The most feasible alternative will be implemented after regrading operations. Soil reconstruction methods will be continually refined to benefit reclamation programs in future years. This paper deals mainly with the objectives of reclamation plots and design and construction methods at Genesee.

2. OBJECTIVES OF RECLAMATION AND PLOTS

The corporate objective in reclaiming lands that are strip mined for coal is to ensure that specific pre-mining land use capabilities are conserved for future generations after mining is complete. The Alberta Coal Policy reflects this objective in calling for "productivity equal to or better than that which existed prior to mining" on reclaimed mined lands.

As previously mentioned, agriculture is the primary land use within the Genesee Power Project permit area. Reclamation plans have been designed to ensure that agricultural land will be re-established following mining activity. Plans will be regularly updated to take advantage of new research and technology.

The establishment of test plots reflects the adherence to regulations stipulated by the Land Conservation and Reclamation Act. The plots also support the requirements of a Development and Reclamation Plan approval issued by the Land Conservation and Reclamation Council based on recommendations from the Development and Reclamation Review Committee of Alberta Environment.

The main objective of the reclamation plots is to determine the most cost effective method of reconstructing agricultural soils during the initial five reclamation years (1989-1994). Beyond that, it is expected that knowledge gained from the 1989-1994 period will contribute to reclamation procedures between reclamation years five and ten. Other objectives are to provide assurance to the local farming population and pertinent government agencies that successful soil reconstruction and vegetation can readily be achieved and to document the current productivity of Genesee soils. Further objectives are to ensure that the same type of

crops that were grown prior to mining may be grown on reclaimed fields; the same types of seeding and fertilizing rates, equipment and other farm management techniques may be employed on reclaimed fields; and crop yields obtained from reclaimed fields, and farm energy inputs to obtain yields will be within the normal local range. Finally, the plots may suggest further research projects assisting in future yield scale reclamation efforts.

A committee, named the Reclamation Review Sub Committee (R.R.S.C.) has been formed between representatives of the local farming community, the District Agriculturalists Office, Edmonton Power and Fording Coal to ensure consistency of reclamation activities, make recommendations regarding reclamation methods and land use, and to address various subjects arising due to reclamation activities.

3. DESIGN METHODS

A. General

The Genesee plots were located (see Figure #2) and designed to investigate alternative soil profiles that could be reconstructed during reclamation operations. In all cases, topsoil was salvaged prior to plot construction and evenly distributed over the established plots. Of particular interest is the quality and quantity of subsoil materials utilized in the plots. Monitoring over the life of the plots will assess the effects that these subsoil combinations may have on topsoil quality and crop yield.

Subsoil combinations utilized in the plots represent the two parent materials found on the prime area. These are lacustrine and glacial till. Current soil profiles in the mine area have developed from lacustrine or glacial till. Subsoil combinations in the plots represent these materials. Three treatment combinations were constructed based on depth of subsoil. Each combination is replicated three times for statistical purposes.

An integral part of the design at Plots 2 and 3 is to determine the thickness of subsoil materials required for use above dragline spoil.

The two major bedrock units in the mine area, the Horseshoe Canyon and Paskapoo Formation, are also represented in the plots.

During the mining process, bedrock materials will be mixed with overlying glacial till and lacustrine. This mixture results in the spoil surface upon which surface soil profiles will be constructed.

RECLAMATION PLOTS

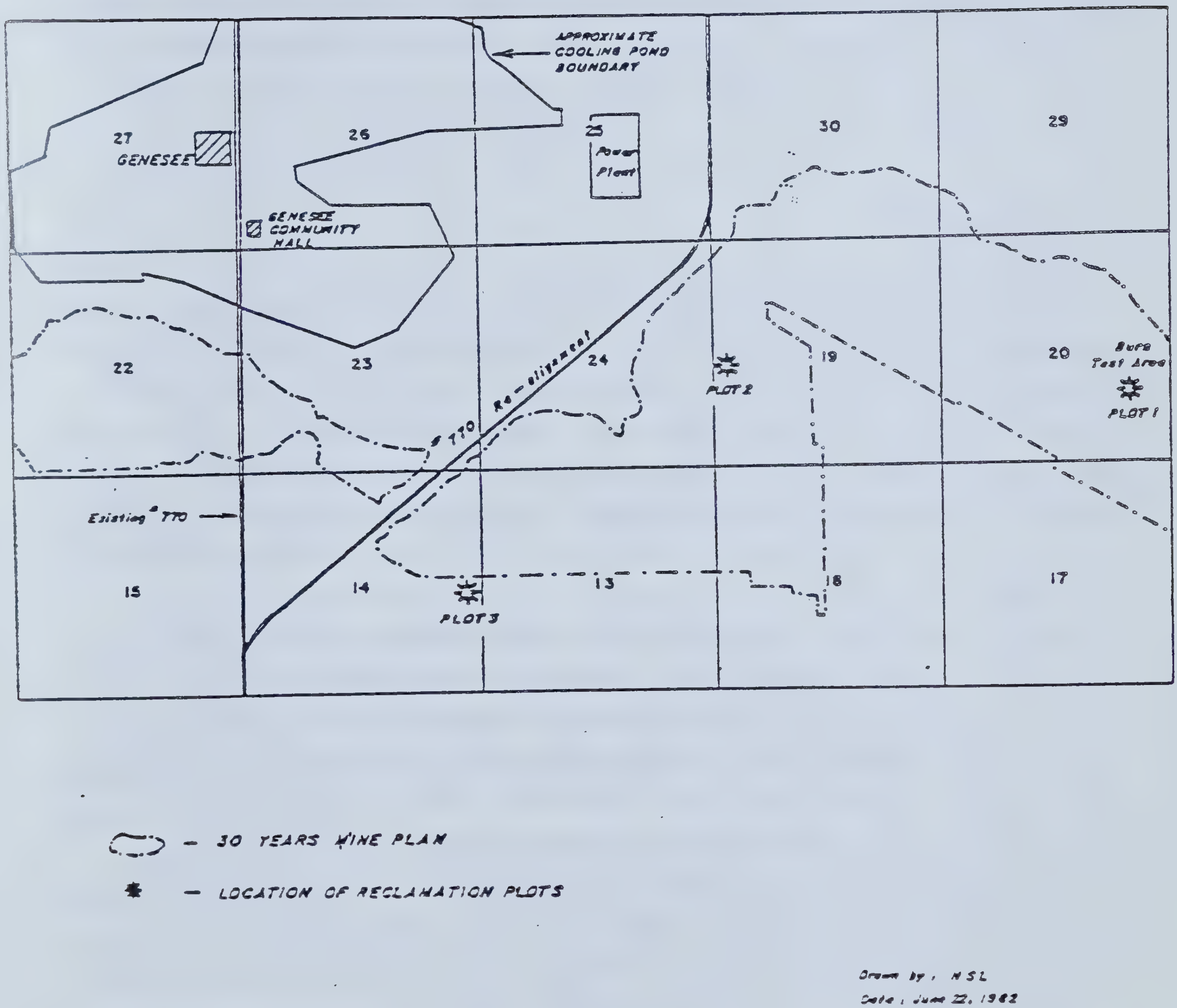


Figure #2

B. Plot 1

Plot 1 is located (see Figure #3) on a backfilled trench from which a sample of coal was extracted to perform burn tests during 1980. The sequence of geology at Plot 1 is representative of a large portion of the eastern mining block. (See Figure #4)

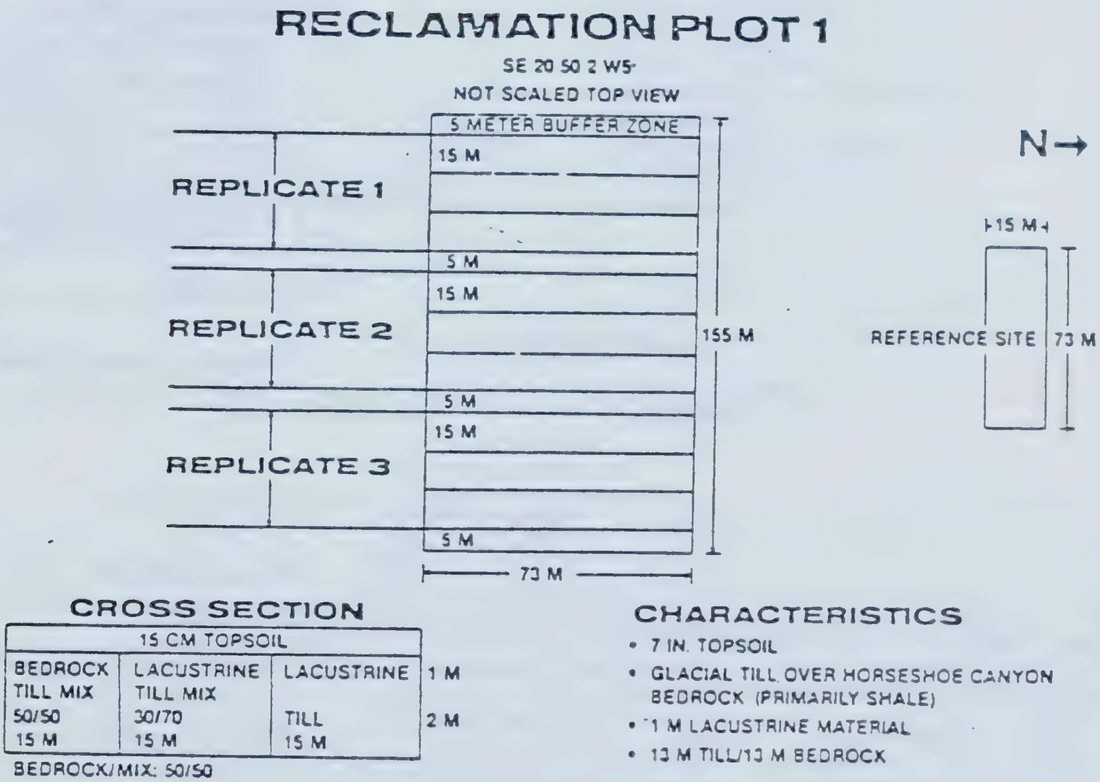


Figure #3

CROSS SECTION - PLOT 1

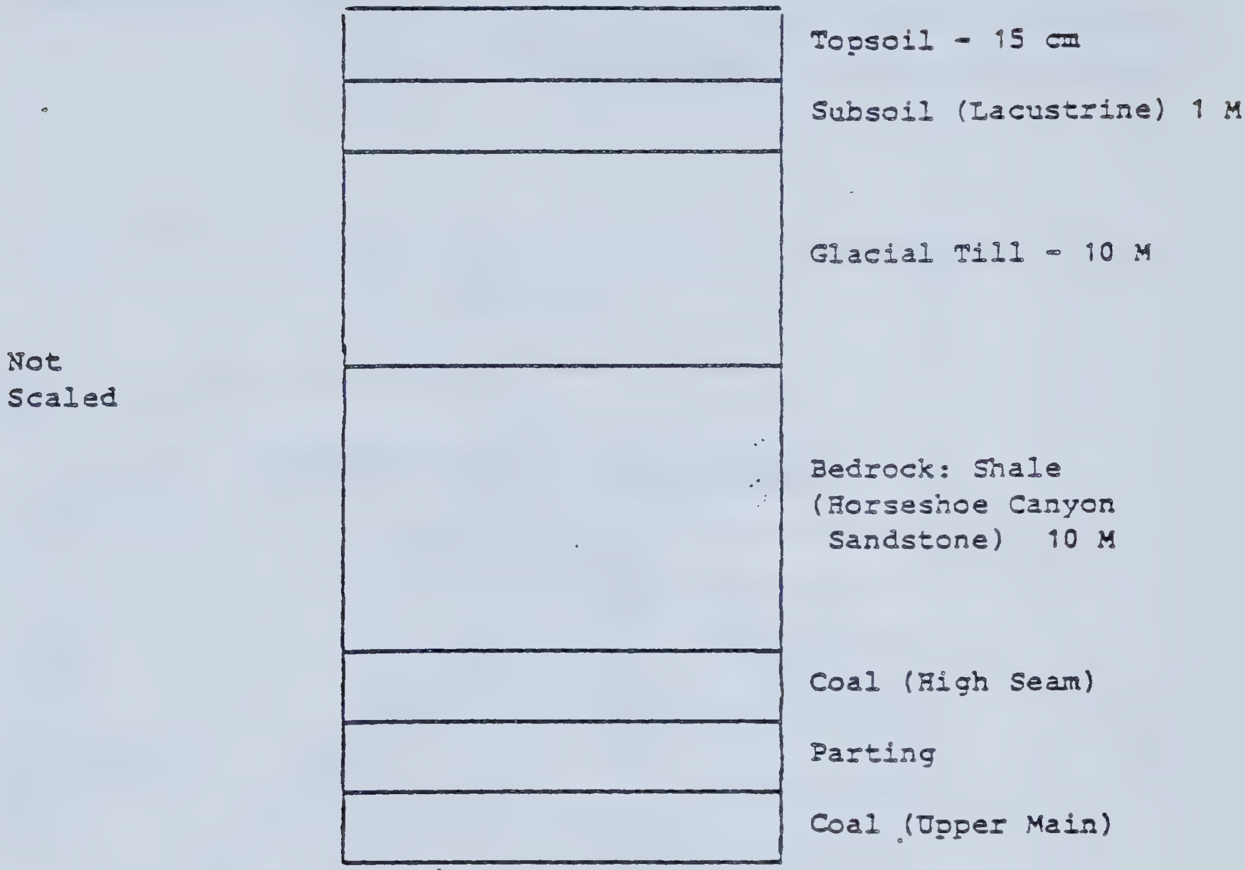


Figure #4

The plot design represents the geological sequence that will be produced during mining. This will be a 1:1 mixture of glacial till/shale bedrock.

C. Plots 2 and 3

Plots 2 and 3 were constructed at locations which provided geological materials representative of the remaining portions of the mine area. Plot 2 provided soft sandstone of the Horseshoe Canyon Formation while Plot 3 provided very hard Paskapoo Formation sandstone. (See Figures #5 and #6)

The latter material mainly consists of a band of well cemented sandstone concretions between beds of soft sandstone. (For geological sequences for Plots 2 and 3, see Figure #7). Both plots were based on a 2:1 mixture of bedrock/till.

RECLAMATION PLOT 2

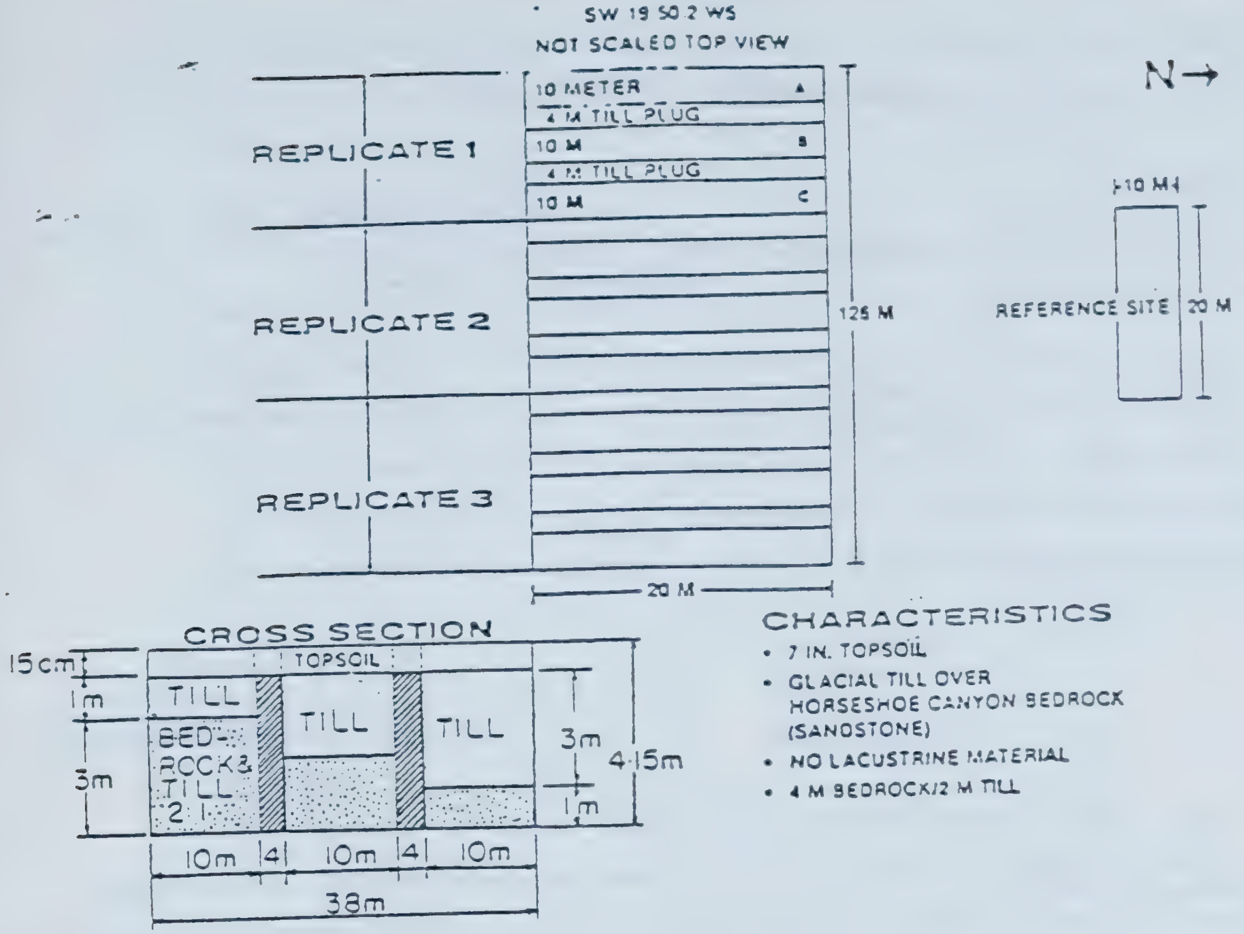


Figure #5

RECLAMATION PLOT 3

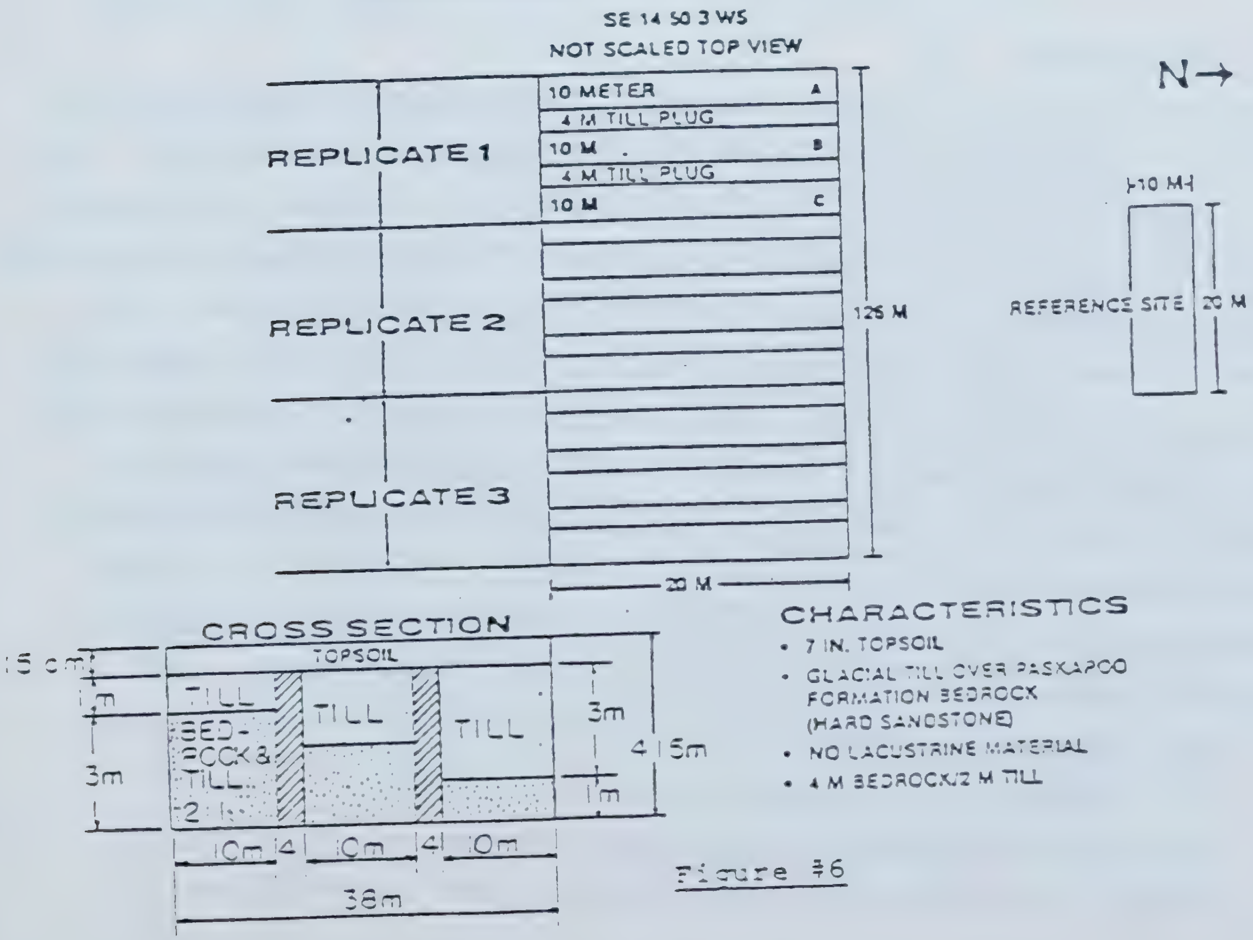


Figure #6

CROSS SECTION - PLOTS 2 AND 3

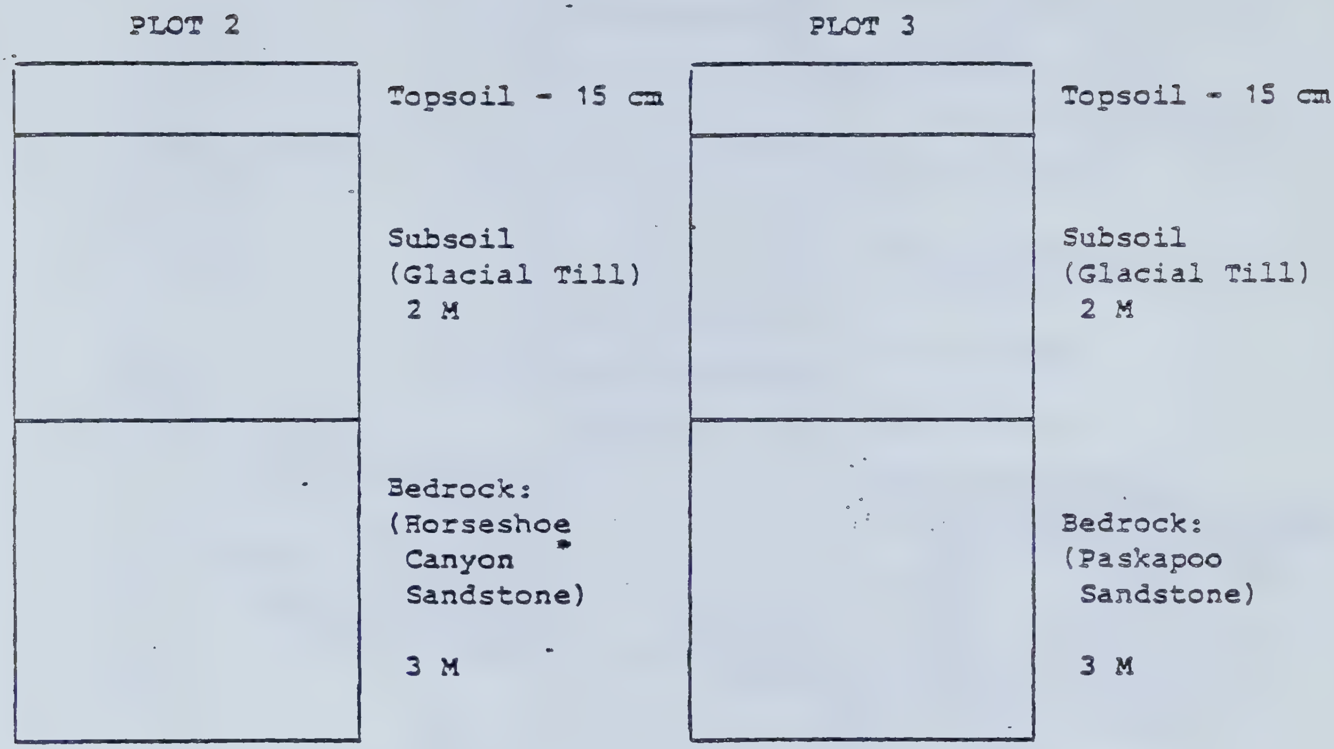


Figure #7

D. Limitations

For the actual mining phase, successful reclamation will be dependent not only on satisfactory soil profile reconstruction, but as well as slope, aspect and chemical/physical characteristics of the regraded spoil surface that will underlie the salvaged layers of soil. The plots described in this paper cannot totally represent all possible reclamation systems.

Until re-graded surfaces become available during the mining phase for further field scale trials, the plots described here will provide the best possible data on surface soil profile reconstruction. The results will provide information for use in materials handling decisions made for the first ten years of mining (1986-1996).

Some factors which cannot be properly represented in any mining simulations using plots include:

i. Water Trap Effect

Because of variations in compaction between disturbed materials and undisturbed materials beneath and bordering the plots, the water table in the plots may not represent the

probable situation on a reclaimed mine surface. Piezometers have been installed inside and outside each plot area to monitor this effect.

ii. Spoil Variation

In the mining phase, regraded spoil surface mixtures may vary considerably depending on overburden variability and mining sequence. The plots designed here are each representative of one spoil surface mixture. During actual mining, potential problems which may result from overburden quality variability may be minimized by regular examination of the highwall and modifying mining procedures and/or reclamation accordingly.

4. CONSTRUCTION METHODS

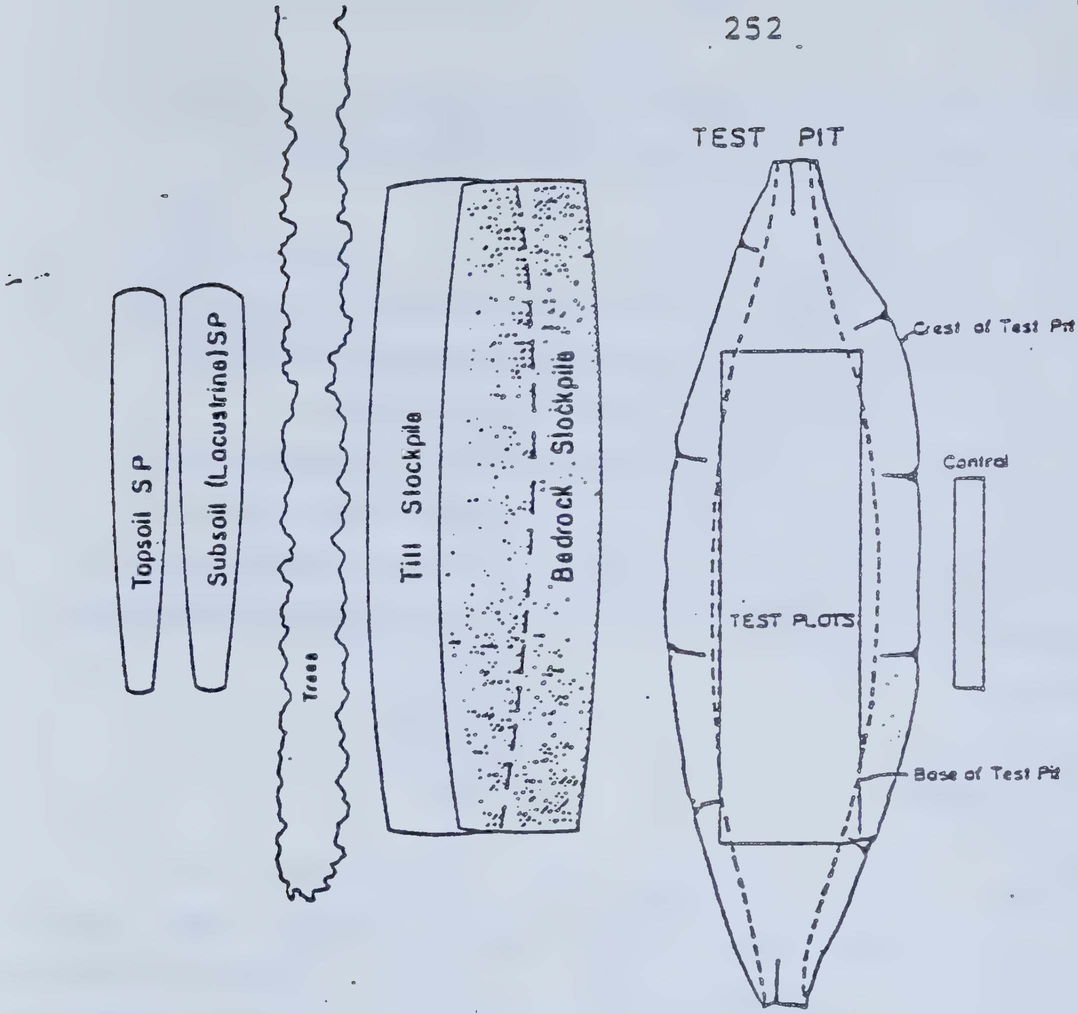
A. General

The construction of Plot 1 was completed in July of 1981. The construction of Plots 2 and 3 was completed during November, 1981. All plots were topsoiled in the Spring of 1982. A crawler backhoe was utilized for initial soil testing. Equipment used during construction consisted of 3 scrapers and 4 crawler dozers.

B. Plot 1 (See Figure #8)

This plot was constructed on top of the bulk sample pit. Materials had been moved from the pit, segregated and stockpiled the previous year. Backfilling operations were tightly controlled to meet the design requirements of Plot 1. Backfilling was initiated with bedrock materials ten (10) metres from the surface, a 1:1 mixture of bedrock/till was started and this was continued to within 4 metres of the surface.

Correct placement of separately stockpiled materials was achieved by assignment of the appropriate ratios of scrapers to each stockpile. One complete replicate was constructed before commencing another, thus three treatments were constructed simultaneously along with an appropriate buffer between. Scrapers continually hauled fill while in pit dozers placed it and maintained a level surface in each replicate.



PLAN VIEW OF CONSTRUCTION LAYOUT
1 S.E. 20-50-2-W5

Figure #8

Once all three replicates were complete, a subsoiler was applied to the surface and was able to rip to approximately 0.5 metres. Ripping was conducted prior to topsoil replacement. Compaction tests on two separate occasions during backfilling indicated roughly 94% of original compaction had been achieved. All pad areas utilized for stockpiles were seeded to a grass/legume mixture following subsoiling and cultivation as follows:

- 6% Majestic Kentucky Blue
- 6% Baron Kentucky Blue
- 6% Sydsport Kentucky Blue
- 9% Nugget Kentucky Blue
- 10% Italian Ryegrass
- 10% Reubens Canada Blue
- 16% White Clover (P.O.)
- 20% Sodar Streambank Wheatgrass

A brillion seeder was utilized, and 23-23-0 (N-P-K) fertilizer broadcast at 75 kg/ha (prior to cultivation).

C. Plots 2 and 3 - Excavation (See Figures #9 and #10)

Excavation procedures were as follows:

1. To salvage and store topsoil from both plot and stockpile area.
2. Excavate and stockpile subsoil material from plot area.
3. Excavate and stockpile bedrock material from plot area.

Bedrock encountered at Plot 2 was soft Horseshoe Canyon Formation sandstone. It was weakly cemented and loaded easily into scraper buckets. The excavation depth at Plots 2 and 3 averaged approximately 4 and 5 metres respectively. These depths were required to recover enough subsoil and bedrock material to supply the mixtures specified in the plot design.

In order to achieve the bottom 2:1 bedrock/till mixture, each motor scraper was assigned a particular duty. Two scrapers loaded bedrock material and the other scraper loaded till material. The machines then deposited their material in equal lifts into the bottom of the pit. Each lift was then ripped to mix the material. This procedure was followed until the desired backfill depths were achieved.

The next phase of construction involved selectively placing subsoil material in each treatment. Till plug buffers were installed between treatments. Each scraper operator was designated a particular treatment to construct. This procedure was effective as each operator could construct the same treatment in each replicate, minimizing confusion. Ripping was carried out continually during construction to avoid compaction and ensure proper material mixing.

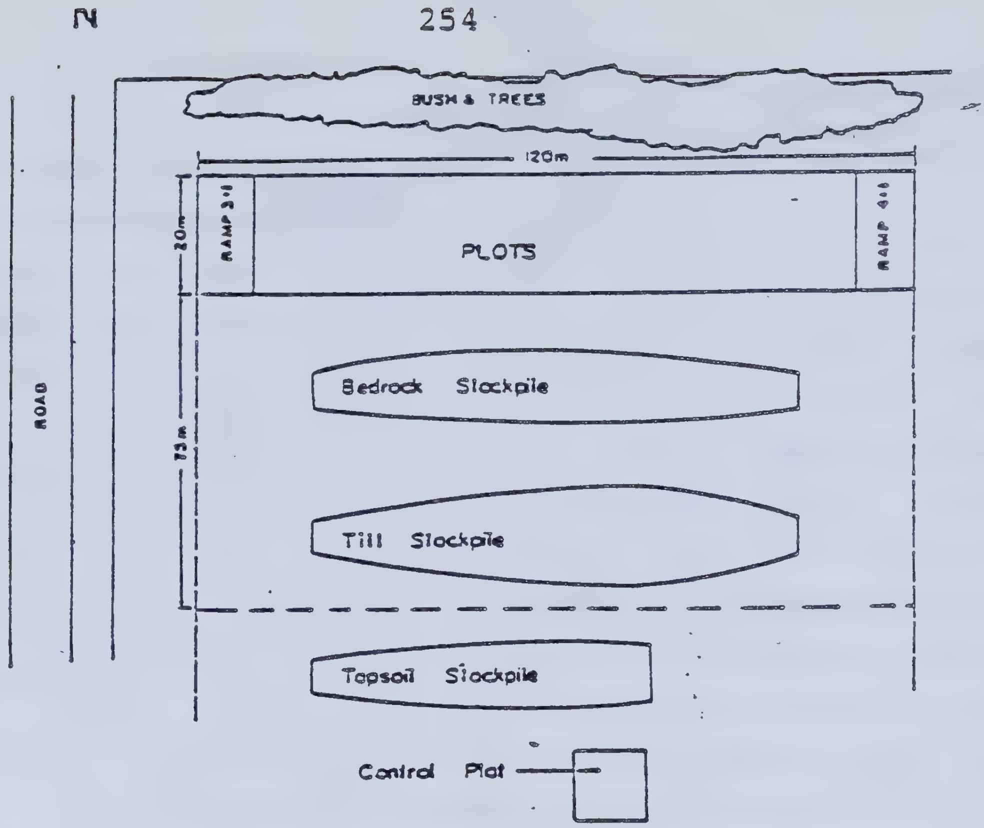
The plots were allowed to settle during the winter and spring and topsoil was replaced during early May, 1982. Seeding and fertilizing was conducted within the first week of June, 1982. Stockpile areas were topsoiled and ripped, avoiding compaction and therefore facilitating agricultural use.

5. MONITORING AND MAINTENANCE

A. Monitoring Procedures

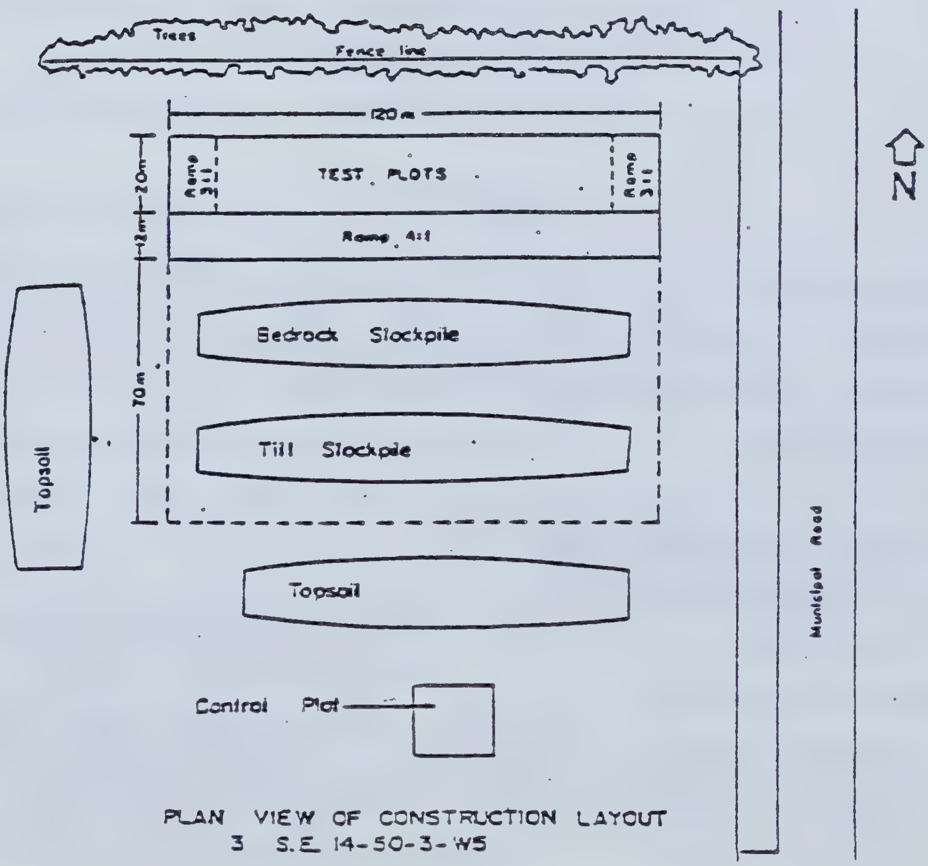
Plot monitoring procedures will include reference site observations. Monitoring will include:

1. Periodic sampling of the soils down to the water table in Plot 1, and to 5 metres in Plots 2 and 3. These samples will require routine salinity analysis so that salt movements may be monitored.



PLAN VIEW OF CONSTRUCTION LAYOUT
2 S.W. 19-50-2-W5

Figure #9



PLAN VIEW OF CONSTRUCTION LAYOUT
3 S.E. 14-50-3-W5

Figure #10

2. Water table observations using standpipes in each replicate and reference site, and piezometers in each reference site. This will determine whether or not subsurface water movements within the plots are abnormal, and whether they will adversely upset normal salt movements in the soil.

3. Annual yield results of both barley and forage crops. Statistical analysis will provide comparisons between treatments within each plot but not between plots. Each plot represents a unique geological sequence, and stands alone as a separate experiment. Analysis of variance will be used to identify sources of variation, and, Duncan's Multiple Range test will be used to determine the significance of any differences.

B. Maintenance Procedures

The plots will be seeded as follows:

1. 1/3 forages with a barley cover crop.
2. 2/3 barley.

The 1982 program consists of a Bonanza barley application to every plot and a #2 Pasture forage mix consisting of Brome grass, Alfalfa, and Timothy. This is the standard mix used in the Genesee area.

Fertilizer rates will be consistent within each plot and are standard area rates recommended by Alberta Soil and Feed Testing Laboratory procedures. Rates are also representative of those used by local farm managers.

The 1982 program uses a 23-23-0 mixture applied at 40 kg/ha. A plot harvester will be used to thrash grain, and forages will be cut with a power cutter bar and weighed on site. Samples of forage will be dryed and weighed for biomass determinations.

Plot maintenance procedures will reflect actual farming methods in the area with the exception of cropping sequence. Continous cropping procedures will be used with cultivation in the spring and fall. This is required to provide as much data as possible prior to mining. Annual date comparisons are necessary considering the limited time span before reclamation of the mine begins.

Annual programs and progress reports will be continued. Data and the relation to previous reports will be discussed until the plots provide conclusive results or they are superseded by full scale field reclamations or until they are mined.

6. SUMMARY

Reports are to be made available, for review, to necessary Alberta Government agencies and local representative of the R.R.S.C. It is proposed that an Open House be held in the community, in late summer. Observation of the plots will be included in order to update interested individuals on information being provided by the plots.

It is believed that the reclamation research procedures described in this paper will provide essential data for selecting the most cost effective alternative for field scale reclamation and the construction of agricultural soils at Genesee.

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A NEW DIRECTION IN MINE RECLAMATION

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ABSTRACT

The paper will address current mine reclamation objectives with an overview of new programs being initiated by the company. Programs that include better land use by planting cash crops, tree farming and the results of the company's initiative in greenhouse and aquaculture technology, will be described.